MANUAL

OF THE

PHYSICS OF PHYSIOLOGY.

PEYSER.

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PREPARED FOR STUDENTS OF MEDICINE.

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PHYSICS.

Physics, or Natural Philosophy, is that science which deals with the laws governing matter. *Matter* is anything that exists. By the *Conservation of Matter* is meant that nothing material is ever destroyed. Water, e. g., descends from the clouds in the form of rain, is gathered up in rivers, flows to the seas, evaporates, ascends and forms clouds, and again descends as rain. Neither is energy wasted. When one form, as electricity, or mechanical energy, disappears, another form, as heat, takes its place. This is the *Conservation of Energy*.

ELECTRICITY.

CHAPTER I.

ELECTROSTATICS.

The principal methods of developing electricity are by friction, chemical energy, and action of magnets.

Frictional Electricity.—If a glass rod be rubbed with wool or cat's fur, and brought near a pith ball, the latter will be attracted until it touches the rod, when it will immediately fly away. If now a stick of sealing-wax which has been rubbed, be brought near, the ball will again be attracted until it comes in contact, when again it flies away. Now, it will be attracted by the glass rod until contact is made, and the former behavior is repeated.

Vitreous electricity is developed in the glass rod, and *resinous* electricity in the wax.

Laws of Electrical Attraction.—Like electricities repel; unlike attract, and the force is in inverse proportion to the distance.

The *one-fluid theory* supposed that only one kind of electricity exists in body, the body being positively (+) electrified when the fluid is in excess, and negatively (—), when diminished.

The *two-fluid theory*, now generally accepted, supposes that all bodies posssess a certain amount of two kinds of electricity, *positive* and *negative*. When the two are equal, the body is said to be neutral, and positively or negatively, electrified when one or the other is in excess, as the case may be, the total amount being always the same.

The rubbing body develops electricity, also, and the nature of the electricity developed depends on the rubber as well as the thing rubbed.

Glass receives a positive charge when rubbed with silk, but negative, when rubbed with cat's fur.

Positive is equivalent to vitreous, and negative, to resinous electricity.

Ideoelectrics and Anelectrics.—It was formerly supposed that only certain bodies, as cat's fur, wool, glass, silk, sealing-wax, sulphur, guttapercha, etc., could be electrified, and they were called ideoelectrics. Metals, carbon, water, watery saline solutions, it was thought could not be electrified, and they were called anelectrics. The terms now used are *non-conductors* and *conductors*, the former being synonymous with ideoelectrics, the latter with anelectrics. But no body is absolutely one or the other. Some bodies conduct very badly, others generate very badly, so that the terms are but relative. The former retain electricity, while the latter conduct it so well that it disappears as soon as formed on the surface. If a conductor, as iron, be joined to a nonconductor, as glass, and the iron be rubbed vigorously while a hand holds the glass, electricity is developed, diffuses itself over the surface and tends to escape, but is prevented from doing so by the glass. A bad conductor united in this way to a good conductor is called an *insulator*.

The best conductors are the metals, and following them are carbon, plumbago, acids, saline solutions, animal fluids, water, animal and vegetable tissues, moist stones and earth. The best insulators are those substances named under ideo-electrics, and porcelain, paper, oils, dry air and wood.

The **human body is a conductor** in virtue of the water it contains.

A charged body loses its electricity by convection.

Electricity accumulates solely on the surface of conductors. If the body is round, the density of the electrical layer is equal at all parts of the surface; if oval, it accumulates in greater amount at the pointed extremities, and if one of the ends be extremely pointed, the accumulation may be so great that the electricity tends to pass off from the conductor into the atmosphere, the *tension* being considerable.

Induction is the term applied to the influence exerted by electrified upon unelectrified bodies. If an insulated conductor charged, say with positive electricity, be brought near an uncharged insulated conductor, negative electricity will be induced in the end nearer the former, while positive electricity will be driven to the further end. Near the centre, will be the neutral zone. Touching the further end, the repelled electricity being free, will escape. Removing the finger, and the charging body, the bound negative electricity will become free, and the conductor will have received a charge.

Influence or Static Machines are constructed usually of discs of glass or rubber. The principle involved is that of induction.

Condensers are instruments for concentrating a large quantity of electricity on a small surface, an action effected by induction. Such an apparatus is the Leyden jar, which is a glass bottle coated inside and outside with tinfoil up to a few inches from the neck. Through the stopper of cork or wood passes a metal rod terminating outside in a knob, and prolonged inside by a chain touching the inner lining. The jar is charged by holding it so that the hand touches the coating and presenting the knob to the conductor of a friction machine. An *electric battery* may be formed by placing in a box lined with foil, a number of the jars with their outside coats in contact. The foil should be connected with the handle of the box which should have an earth connection. The knobs are connected and presented to a prime conductor.

CHAPTER II.

CURRENT ELECTRICITY.

The *nature* of current electricity is not exactly known, but like light and heat, it is assumed to be due to vibrations of luminiferous ether.

Electromotive Force.—When two dissimilar metals are brought into contact, there ensues a disturbance of equilibrium which is called difference of potential, one of the plates being acted on, the other not. The same disturbance occurs in the dynamo-electric machine. The force produced is called electromotive force or the force which tends to set electricity in motion so as to cause an electric flow. The force is abbreviated E. M. F.

Methods of Production.—(1) Mechanical action, as by dynamos, frictional and electrostatic induction machines. (2) Chemical action, as by Voltaic or primary cells, and charged storage, or secondary cells. (3) Radiant energy, as thermo-electric cells. (4) Vital energy, as from an animal or plant.

Voltaic cells may be divided into two general classes, (1) single fluid, (2) double fluid.

Each consists of two essential parts, (1) a *voltaic pair* or *couple*, and (2) an exciting liquid called the *electrolyte*. The double fluid cells have two electrolytes. The two substances forming a voltaic pair are called the elements of the cell. These are in the form of plates or rods and are known as the *positive* and *negative plates*.

Production of Current.—Chemical action takes place when the part of the plates projecting, called the *poles*, are connected by wire, it occurring between one or both electrolytes and one of the plates, the result being that this plate, the positive, is gradually dissolved, or enters into combination with part of the electrolyte, the other plate being unaffected.

Polarization of Plates.—Because of decomposition, hydrogen is liberated and tends to collect on the negative plate. If this be permitted, there is a decrease of current. Elements devised to overcome this difficulty are called *constant*.

Prevention.—In the double-fluid cell, the second fluid surrounds the negative plate and is for the purpose of combining with hydrogen and so preventing its liberation. In some single-fluid cells, a solid substance is in contact with the negative plate, that is capable of combining with the hydrogen. *Amalgamated Zinc* also tends to prevent polarization.

The *materials for the pairs* of voltaic cells are of great variety, the most important being zinc, carbon, copper, lead, silver and platinum. Of these, zinc nearly always forms the positive element, i. e., it forms a couple with either of the other substances named.

Direction of Current.—When a cell has its *circuit closed*, the E. M. F. produced causes a current to flow through such a circuit. The point at which it is assumed to leave the cell is called the *positive pole*, and the point at which it is assumed to re-enter after having passed through the circuit, the *negative pole*. The positive pole of the cell is that connected with the negative plate, while the negative pole is that connected with the positive plate.

The *standard of E. M. F.*, or unit, is called the *volt*.

Forms of Voltaic Cells.—*Daniell's* consists of a perforated copper cylinder, open at both ends, immersed in a saturated solution of copper sulphate. Within this is a porous earthenware vessel containing dilute sulphuric acid in which is immersed a cylinder of zinc. When in action, the acid attacks the zinc, forming the sulphate, and liberates hydrogen which reduces the copper sulphate, and the resulting copper is deposited on the copper plate, while the hydrogen combines with the acid radical to form sulphuric acid. Copper sulphate, which is alone acted upon, is replaced by crystals of the salt which rest on a small shelf on the copper cylinder.

The *gravity element*, a modification of the Daniell, consists of a plate of copper in the bottom of the vessel, on which is poured a saturated solution of copper sulphate. A "crow-foot" of zinc is suspended from the top of the container and covered by a solution of zinc sulphate.

The *silver-chloride* has a zinc-silver couple immersed in a sal-ammoniac solution. The silver plate has the form of a wire surrounded by a fused mass of silver chloride. The plates are kept apart by a thread and a block of wood. The E. M. F. of this cell is nearly uniform, and has a value of about 1.03 volts. It has the disadvantage of being small.

The *Leclanche* has a zinc-carbon couple immersed in a solution of sal-ammoniac, but the carbon is surrounded by solid peroxide of manganese which combines with hydrogen and prevents polarization. It has the advantage of furnishing a strong current for a short time, the E. M. F. being about 1⅓ volts.

The *Grenet*, or *bichromate*, has a zinc-carbon couple immersed in a solution of bichromate of potash, water and sulphuric acid. Even when not in use, the fluid acts on the zinc, so provision is made to lift out the zinc when the circuit is open.

The *Edison-Lalande* has a zinc-copper couple immersed in a solution of caustic soda, or potash. To prevent polarization, a plate of compressed copper oxide is placed in contact with the copper plate. Liberated hydrogen combines with oxygen of the oxide. This cell furnishes powerful currents for a considerable time without much polarization, but its E. M. F. is only about ⅔ of a volt. For heating electric cauteries, a modification, consisting of a large copper plate between two zincs, is used.

In the *dry cell*, the liquid is absorbed by a gelatinous or pulverulent material. Usually there is a zinc-carbon couple. The E. M. F. varies from ⅔ to 2 volts.

Storage or *secondary* cells have such elements and electrolytes that, after the cells are completely exhausted, they are capable of being *recharged* by the passage of an electric current in a direction opposite to that they furnish when charged. Commonly, they consist of a couple of porous lead and lead peroxide immersed in dilute sulphuric acid.

CHAPTER III.

RESISTANCE.

Electric resistance is that which opposes the flow of electricity through a circuit. The amount of resistance depends upon (1) the nature of the conducting material, (2) its length, (3) its cross-section. There are two resistances in a circuit, (1) *internal*, or that of the cell, (2) *external*, or that of the external part of the circuit.

Laws of Resistance.—(a) Internal resistance is inversely proportional to the size of the plates, and directly to their distance apart. (b) External resistance is directly proportional to the length of the conductor, and inversely, to the cross-section.

The **unit** of resistance is the *ohm*, defined as the resistance of a column of pure mercury 106.3 cm. long, and 1 sq. mm. in cross-sectional area, at 0°C. Roughly, it is the resistance offered by two miles of ordinary copper trolley wire, or by one foot of copper wire No. 40 A. W. G., having a diameter of .003145 in. at 45°F.

Modes of Joining Cells.—(1) *Multiple arc*, or *parallel*, where all the positive poles joined together, form the positive electrode, and the negative plates joined, form the negative electrode. (2) *Series*, where the negative pole of one cell is joined to the positive of another, and so on through the set, leaving vacant the positive of the first, and negative of the last cell. Wires joined to these form the electrodes.

Divided Circuits.—If a wire be joined to a second wire, so that the current passes first through one and then the other, they are said to be *connected in series*, and the total resistance of the series will be the resistance of one plus that of the other. If they be *connected in parallel* so that the current divides between them, the joint resistance will be the mean resistance divided by two.

CHAPTER IV.

The **unit quantity** of electricity, i. e., the amount of electricity passing through a circuit in a given time, is called the *coulomb*. The electric *unit rate of flow*, or unit of current strength, is called the *ampere*, equal to one coulomb-per-second.

Ohm's Law.—$\text{Amperes} = \dfrac{\text{Volts.}}{\text{Ohms.}}$

The importance of this law may be demonstrated when, having a given amount of resistance, one wishes to know the E. M. F. required to maintain a certain rate of flow. Will joining in arc or series be of greater benefit?

In arc, say with six cells, according to a former statement, we would practically have a single cell six times the size of one of them, and as the internal resistance is inversely proportional to the size of the plates, it is diminished to one-sixth. Increased E. M. F. is obtained. When joining in series, we not only increase the amount of E. M. F., but also the internal resistance. There is apparently no advantage.

Suppose we consider both resistances, and state the formula, $A = \dfrac{V}{O+o}$ where O is the internal, and o the external resistance.

(1) Have the cells in a circuit where the external resistance is so small in comparison, it may be neglected, and join in arc.

$$A = \frac{V}{\frac{O}{6}+o}. \qquad o = \text{nothing; then} \qquad A = \frac{6V}{O},$$

i. e., the current is six times as great.

(2) Where the external resistance is the greater, there is no advantage; except when joined in series, for

$A = \dfrac{6V}{6O+o}$. The internal resistance may be neglected, then $A = \dfrac{6V}{o}$.

CHAPTER V.

INDUCTION.

If a continuous wire be brought in the neighborhood of another through which electricity is flowing, a current will be produced in the former when the current of the latter is turned on (*made* or *closed*) or off (*broken* or *open*).

The latter is the *primary*; the former the *secondary circuit*. This is induction. Currents also appear in the *secondary circuit*, when the strength of the primary is increased or decreased; and when the distance between the two is increased or decreased. To increase the effect of induction, instead of using single wires, insulated wire is wrapped on bobbins, so as to form coils, the primary being of thick wire, comparatively short, and capable of slipping into the secondary of thin wire and great length. Such coils are called *induction coils*.

Direction of Induced Currents.—This obeys Lentz's law, viz., the direction of the induced current is always tending to oppose change in the primary circuit.

The **varieties of induction** are (1) self-induction, (2) mutual induction, (3) electro-magnetic induction, (4) magneto-electric induction. All obey Lentz's law.

In a single coil, the various turns of wire serve to induce currents, when the flow is made or broken. This is *self-induction*. *Mutual induction* is spoken of above.

Magneto-induction.—If a magnet be thrust into a secondary coil, a current passes at the time, and also when the magnet is removed, but not while it is stationary; or if the magnet be stationary and the coil moved, currents are produced.

Electro-magnetism.—If a bundle of iron wires be placed within a coil, through which a current is flowing, magnetism will be developed in it.

The **Ruhmkorff Coil** is based on the principles enunciated. To make and break the current rapidly, an apparatus called interrupter or rheotome is provided. This consists of a spring to which is attached at its upper part a piece of soft iron, called the armature. When the current is made, it passes through the primary coil, converting the iron wires into a magnet which attracts the armature, and the current is broken. The armature being released, it flies back, makes contact, and again the current is made. Currents are at the same time, induced in the secondary coil.

The current at the break is more powerful than at the make.

DuBois-Reymond's Inductorium.—In this, the secondary can be moved on, or away from the primary coil. The interrupter may be thrown out of the circuit. There is an arrangement for diminishing the difference between the two currents.

Varieties of E. M. F.—(1) *Alternating* (a) Symmetrical. (I) Sinusoidal. (II) Non-sinusoidal. (b) Dissymmetrical. (2) *Continuous*. (a) Pulsating. (I) Intermittent. (II) Non-intermittent. (b) Steady. These may also represent the varieties of currents.

CHAPTER VI.

EFFECTS OF THE ELECTRICAL CURRENT.

(1) **Thermal.**—Heat always attends the conduction of a current because of resistance present.

(2) **Electrolysis.**—Electric decomposition. Explanation. Nomenclature.

(3) **Electro-magnetism** (see Chapter V).—Residual-magnetism.

(4) **Cataphoresis.**

(5) **Luminous.**

CHAPTER VII.

KEYS, ELECTRODES, &c.

A galvanic key or switch is for the purpose of rapidly and easily making or breaking a circuit. Varieties: (1) Contact. (2) Spring. (3) Friction, or short circuiting.

Unipolar Induction.—Static electricity of some tension, generated in a secondary coil, may be set free, if a path is opened for it, and produce contraction. Method of prevention.

Commutators may act as double switches or pole changers.

CHAPTER VIII.

MUSCLE AND NERVE STIMULATION.

Nerve-muscle Preparation.

Muscle Telegraph.—An appparatus for indicating when a muscle contracts.

Physiologic Effects of Currents.—(1) Continuous currents do not stimulate to contraction, while (2) interrupted currents do. (3) Induced currents are more stimulating than continuous, and if repeated rapidly induce tetanus. *Tetanus* is a fusion of successive contractions into one continuous contraction.

Direct stimulation is that applied to muscles, *indirect* that applied to nerves. The latter is productive of greater effect than the former.

Secondary Contraction.—The nerve of a nerve-muscle preparation is laid over a second muscle, touching partly tendon and partly muscular fibre. Single induced shocks applied to the first will cause contraction of the second preparation.

CHAPTER IX.

ELECTROTONUS.

Electrotonus is a condition of altered excitability produced in a nerve by the passage through it of a constant current.

Katelectrotonus is a condition of increased excitability existing in a nerve at the cathode or negative pole. **Anelectrotonus** is a condition of diminished excitability existing in a nerve, at the anode or positive pole.

The **rheocord** is an apparatus consisting of a number of wires, for increasing or diminishing the amount of current going to the preparation. It is always connected in short circuit.

To show the effects of electrotonus, there are necessary: (1) a *constant* current for throwing the nerve into an electrotonic state, (2) an apparatus for varying the current strength—the rheocord, (3) a means of reversing the current for sending it up or down the nerve—the commutator, (4) a current for stimulating the electrotonized nerve—an induction current, and (5) an arrangement for stimulating near or far from the muscle—another commutator.

When the nerve is stimulated between the electrotonizing electrodes and the muscle, it is said to be *myopolar;* beyond the electrotonizing electrodes, *centropolar.*

Effects of Electrotonus.—(1) When stimulation is *myopolar* and in the region of the *cathode,* (the current is passing down the nerve), tetanus appears—there is katelectrotonus. (2) Still myopolar, but stimulating in the region of the anode (the current is passing up the nerve), tetanus disappears—there is anelectrotonus. (3) When the stimulation is centropolar and in the region of the anode (the current passing down), tetanus disappears—there is anelectrotonus. (4) Still centropolar, but stimulating in the region of the cathode (the current passing up), tetanus appears—there is katelectrotonus.

LAWS OF CONTRACTION.

	Weak stream.		Medium stream.		Strong stream.	
☝	Cl.—c.	Op.—r.	Cl.—c.	Op.—c.	Cl.—r.	Op.—c.
☟	Cl.—c.	Op.—r.	Cl.—c.	Op.—c.	Cl.—c.	Op.—r.

The excitability of a nerve increases as the nerve dies, and reaches a maximum just before it finally disappears.

Normal Formula.—The contraction on closure at the cathode is greater than the contraction on closure at the anode, which is greater than the contraction on opening at the anode; and this, in turn, is greater than the contraction on opening at the cathode.

CHAPTER X.

MAGNETISM.

Magnetism, as electricity, is believed to be an active condition of the universal ether, and they are so related that the following appear to hold generally: (1) A motion of electricity invariably produces magnetism. (2) A motion of magnetism invariably produces an E. M. F.

A **magnet** is a body that has the power of attracting iron. It may be *natural* or *artificial.* Attraction is greatest at the ends and vanishes at the neutral zone. The ends are termed *north* and *south pole* respectively.

Laws of Magnetism.—Like poles repel; unlike, attract.

Two fluids, positive and negative, are supposed to exist in magnets.

Magnetic Induction is the power possessed by a magnet of attracting magnetism in an unmagnified body, and results in the production of either a *permanent* or *temporary* magnet.

Magnets may be straight, called *bar-magnets*, or *bent*, called *horse-shoe magnets*. The strength is preserved by placing across the poles a piece of soft iron, called a *keeper* or *armature*.

Magnetism is also induced when an electric current is sent around a piece of soft iron. Very strong magnets are made by wrapping around a piece of soft iron, shaped like a horse-shoe, insulated wire, wound in one direction. A current sent through such an apparatus is capable of raising heavy loads.

Paramagnetism.—Bodies attracted by either pole of a magnet are said to be paramagnetic, e. g., iron.

Diamagnetism.—Bodies repelled by either pole of a magnet are said to be diamagnetic, e. g., bismuth, gold.

Influence of Electricity on Magnets.—If a current be passed above or below a suspended magnet and parallel to it, the latter will turn at right angles. There is induced magnetism in the conductor which is at right angles to it, and the needle tends to set itself parallel to that magnetism.

The **direction** of the induced magnetism depends upon the direction of the current in the conductor. If the current passes from the observer, magnetism moves in concentric circles in the direction of the hands of a clock, the reverse holding if the current passes toward the observer. If the current passes above the needle from the south to the north pole, the needle is deflected toward the left; and the deflection is increased if the current flows in the opposite direction beneath the needle.

CHAPTER XI.

GALVANOMETERS.

Galvanometers are instruments employed for the detection and measurement of the strength of electric currents. Essentially, they consist of a suspended magnet, surrounded by many turns of insulated wire, the turns having the effect of increasing a current which might otherwise be too weak to cause deflection of the needle.

Astatic System.—For delicate work, the ordinary magnetic needle would be of no service because of the directional influence of the earth. To remedy this, two needles, as nearly alike as possible, are taken and so fixed that the north pole of one is over the south pole of the other. Such a pair is called an astatic system, and can detect a very much feebler current than can a single needle. The ordinary galvanometer consists of a great length of fine copper wire wound on a vulcanite frame, each turn being carefully insulated from its neighbor, and the ends of the wires connected with binding screws. The needles are suspended from a support by a fine silk fibre, so that one is within the coil, the other just above it.

Thomson's galvanometer is made of two coils wound in opposite directions. The needles are arranged in two sets, connected by an aluminum rod, and fixed to the upper one, is a slightly concave mirror. When in use, a lamp-and-scale arrangement is used. Below the scale is a slit, through which a beam of light passes to the mirror, which reflects it to the scale. Movement of the beam indicates that a current is passing. An accessory magnet placed above the galvanometer, is used for damping the oscillation, or for bringing the needles back to their original position.

To those instruments used in therapeutics, the name *milliammeter* is applied, the scale over which the needle moves being marked in milliamperes. There are various forms.

A shunt for the purpose of varying their sensibility and the range of their indications, is provided for many galvanometers.

The **chief use for galvanometers** in physiology is in the detection of electrical currents in living tissues. Obstacles in the way of correct indications are the extreme sensitiveness of the galvanometer which would indicate currents when the various structures are differently arranged. A frequent source of error is *polarization of the electrodes*. Electrodes are the terminals of the conductors, by means of which the current is applied. One form may be made by fastening a wire on either side of a slip of wood of thickness sufficient to keep them the desired distance apart. Coat with paraffin, which when cool can be scraped away until the requisite length of wire is exposed. Or two quills may be packed with insulating material the wires run through, and the quills fastened together. A nerve laid over these electrodes dries rapidly and is destroyed. To remedy this the *moist stimulation tube* is used. It consists of a small glass tube drawn to a point at one end and containing two rings of platinum from which proceed the conductors. The latter pass through a cork in the wide end.

If electrodes of this kind have been immersed in acidulated water for decomposing purposes, it will be found after a time that the polarity has been reversed, i. e., the positive pole has become negative, from accumulation of bubbles of oxygen; and the negative pole, positive from the accumulation of bubbles of hydrogen. This weakens the original current and constitutes the *polarization of the electrodes*. To remedy this there has been constructed a *non-polarizable electrode*, which consists of a flattened glass tube containing a slip of amalgamated zinc. The end of the tube is closed with sculptor's clay moistened, and the tube itself is filled with neutral zinc sulphate solution and mounted on a universal joint. In working, a second one is used, not provided with a support. The ends can be shaped to any desired form.

Natural muscle currents can be demonstrated by connecting two electrodes as described, to a galvanometer, and then touching one to the centre of the longitudinal surface of a living muscle, and the other to the centre of the cut surface. They will be found to pass out of the muscle by its longitudinal surface. In the muscle, they pass from the cut surface to the exterior.

Negative Variation.—The muscle of a nerve-muscle preparation is fixed as above, a switch being placed in the circuit, which as soon as closed, allows the natural current to flow to the galvanometer whose needle is accordingly deflected. The nerve is laid across a pair of electrodes connected through a friction key with the secondary coil of an inductorium, the primary coil being in circuit through an ordinary switch with a Daniell cell. The natural current being indicated, the key of the primary circuit is closed and that of the short circuit opened so that the muscle is tetanized. The needle will then be found to swing back almost to zero.

Natural nerve currents can be similarly demonstrated.

Effect of Electrotonus on Natural Currents.—When the constant current flows in the same direction as the nerve current, the deflection of the needle is increased (positive phase); and when the constant current flows in the opposite direction, the deflection of the needle is diminished (negative phase).

The **latent period** of a muscular contraction is the time elapsing from the moment of application of the stimulating current to that of response. It may be measured by means of the galvanometer.

CHAPTER XII.

RESISTANCES AND THEIR MEASUREMENT.

The current strength in any circuit may be altered by varying either the E. M. F. or the resistance. Instruments for varying the resistance are called *rheostats.*

The **resistance-box** consists of a series of bobbins on which are coiled various lengths of insulated wire, the two ends of which are connected with two different brass plates. Two plates are in connection with binding screws. A current brought to them would pass through all the coils unless the plates be connected, either in pairs or otherwise, when it would pass through the plates, as they offer less resistance than the coils. Each coil offers a certain amount of resistance which is indicated in ohms on the lid of the box between its two brass plates.

Water Rheostat.—Water possesses a high resistivity, and this is taken advantage of in the formation of a water rheostat. A simple form is that of a glass tube filled with water, closed at each end by a rubber stopper through which is passed a copper wire. If the wires from a battery be connected with the wires of the tube, a current will pass in the tube through the water and encounter resistance proportional to the thickness of the layer of water between the two wires.

In another form, binding posts are connected each to a triangular mass of carbon armed at its extremity with a small sponge. In order to vary the resistance, a milled head is turned which, by means of a worm gear, rotates the carbon plates so as to move them into or out of the liquid, and thus vary both the length and cross-section of the liquid column between them.

Carbon Rheostats.—(1) The resisting path is composed of pulverized carbonaceous material pressed into a groove in an insulating plate. A number of brass studs pass through the surface of the insulating plate and make contact with the carbon column in the groove beneath. The length of the carbon column inserted between the terminals can be varied by turning a handle so as to make contact with the brass studs at different portions of the circumference.

(2) Powdered carbon is placed in a chamber provided with elastic sides. The resistance between the top and bottom surfaces of this mass of carbon depends upon the pressure which is brough to bear upon the layer. When the pressure is very light, the carbon particles do not make good electric contact with each other, and interpose a comparatively great resistance to the passage of the current from one to the other. When, however, the pressure is considerable, the particles are brought into more intimate electric contact, and the resistace of the mass is thereby greatly reduced. The pressure in this instrument is varied by turning a milled-head screw.

CHAPTER XIII.

ELECTRO-THERAPEUTICS.

Both the constant current and the induced current are employed in medicine, the former being sometimes termed *galvanism*, and the latter *faradizm*.

The currents used may be generated by dynamos, voltaic cells, induction coils, or by influence or static machines.

The **static current** (from the static machine), sometimes called Franklinic, is of the alternating type. It may be administered (1) by insulating the patient and giving him one of the poles. Sparks can be drawn from that portion of the body it is wished to stimulate. (2) By single shocks from the Leyden jar. With the person on the ground and the positive pole insulated, friction with the negative pole produces very strong sensations. With both the patient and the positive pole grounded, the sensations are increased. *Effects:* (1) Augmentation of temperature and (2) of urea. (3) Diminution of phosphates.

Continuous, or **constant currents**, sometimes called *direct currents*, employed in medicine, are usually generated by voltaic cells. Sometimes, however, the current from an electric-light main is used through the medium of an *adapter*, which is a kind of rheostat.

The apparatus necessary for the application of the current consists of (1) a switch for throwing the desired amount of current into the circuit, and so arranged as not to cause shock; (2) small cells of the Leclanche type arranged in series except for lighting and cauterizing; (3) switch for interrupting; (4) milliammeter, (5) commutator; (6) rheostat. The current is of the pulsating type.

Induced interrupted currents are of the alternating type, and as produced by the ordinary coil, dissymmetrical, of low tension and frequency, the waves being separated by intervals of no current. High tension coils employ a large amount of very fine wire, and the number of interruptions and consequently, currents, is enormous. Currents may be of as high a frequency as 1,000,000,000 per second. The apparatus consists of a Ruhmkorff coil, the ends of which lead to the internal coats of two Leyden jars. The external coats are united by a solenoid (which consists of a comparatively few turns of insulated wire) and a cord in the circuit of which is the body of the operator. The sparks discharged may be several feet in length and represent hundreds of thousands of volts, but owing to their high frequency, are almost painless.

Magneto-electric machines produce symmetrical alternating waves. They consist of a horse-shoe magnet in the neighborhood of whose poles bobbins of wire with soft iron cores are caused to rotate. An induction current is produced as each coil approaches and leaves a pole, so that in one revolution it makes four currents. There is no current when the coils are between the poles, and when they are reversed the current induced is in a direction opposite that of the first.

Physiological Effects of Alternating Currents.—With sinusoidal variations, alternating currents do not produce sharp shocks. (a) With low frequency, they give neither pain, muscular contraction, nor electrolysis, their influence consisting in increased absorption of O and elimination of CO_2. (b) Gradually increased, they provoke energetic contractions, but these, by reason of the regularity of the current, while of equal intensity, are much less painful than the contractions from the induced current. The gaseous exchange can be increased one-fourth without ill effect.

Comparison of the Effects of Currents.—(1) The continuous current does not show any immediate or appreciably objective influence on nutrition. (2) Franklinization increases respiratory combustion, but in a less intense manner than sinusoidal currents. (3) Ordinary faradization with a very feeble, non-sinusoidal, alternating current, can increase respiratory combustion without pain, but with a strong, non-sinusoidal current, produces a fatal electrical tetanus.

The **causes of death by alternating currents** are (1) arrest of respiration, producing asphyxia, and following this, (2) cardiac arrest by elevation of temperature.

Electrical Resistance of the Body.—The various tissues, with the exception of the skin and bones, offer practically the same resistance, the latter having a resistivity two-thirds greater than other tissues, which increases in proportion to their nearness to the surface. Resistance is greatest in the limbs, less in the neck and trunk, and least in the face; and it varies according to the subject and the disease.

Modes of Applying Electricity.—(1) Dry or (2) wet electrodes or skin. *Galvanism* may be applied (1) generally; (2) locally. With (a) an inverse or (b) a direct current, which may be (c) continuous or (d) interrupted.

Faradizm may be applied (1) generally; or (2) locally, and these may be (a) direct or (b) indirect.

The conductors should always be insulated. Electrodes are of various forms adapted to special purposes.

CHAPTER XIV.

APPLICATIONS OF ELECTRICITY.

Electricity is employed in medicine for (A) Diagnosis, and (B) Treatment.

Diagnosis.—(1) To detect alterations of irritability or sensibility. (2) To aid in distinguishing between the forms of paralysis, central and peripheral. Nerves and muscles paralyzed by a central lesion have their irritability unaffected, while those paralyzed by a peripheral lesion have their irritability rapidly diminished and finally abolished. Sometimes, in the latter instance, muscles respond to a galvanic current slowly interrupted.

(3) To detect foreign metallic substances in the body. (4) To unmask malingerers. (5) As a final test of death.

Therapeutically, electricity is employed as a (1) stimulant and counter-irritant, (2) sedative and antispasmodic; and for (3) electrolysis, (4) cataphoresis, (5) metallic cataphoresis, (6) cauterizing, and (7) illuminating purposes, and (8) its magnetic properties.

CHAPTER XV.

RECORDING APPARATUS.

For obtaining tracings of various phenomena, recording apparatus is used in physiological experiments and practical medicine. Records may be had of the time and characteristics of the pulse, muscles, blood pressure, movements of the heart and chest, etc.

A **revolving cylinder** is a valuable adjunct in most observations. It is covered with blackened paper, and made to revolve at a certain speed; or intervals of time are measured by bringing up against it a lever actuated by electricity and regulated by a seconds clock.

The **myographion** is an instrument for registering muscular movements. There are several forms, of which that of *Marey* is specially good. It consists of a plate of cork supported by an upright which is moved along by clockwork. A pithed frog is fastened to the plate, and its tendo Achilles, freed from insertion, is tied to a lever which projects over the plate and impinges upon a rotating horizontal cylinder. If the frog's leg be stimulated, a curve of muscular contraction will be produced by the movement. To stimulate, the sciatic nerve is exposed, and the induced current brought to it by fine platinum electrodes.

The *pendulum myographion*, as its name indicates, has the form of a pendulum. The lower end carries a smoked-glass plate in front and behind. When the pendulum is moved to one side, it is caught there by a projecting piece and fixed. When released, it swings to the opposite side, and is held in a similar manner. In swinging, the glass plate is drawn in front of the steel point of a heavy lever, which is supported by a frog's gastrocnemius whose nerve is laid across platinum electrodes in connection with an induction coil arranged for giving single shocks. With a time tracing on the plate, it can be demonstrated that a muscle does not contract immediately upon receiving a shock. The time that elapses is the *latent period*.

The **tambor, or drum,** is used for obtaining tracings of the movements of the heart, the pulse, etc. Its modifications for special purposes will be described later. The instrument consists of a shallow box of metal, provided with a tube. Above, the box is closed by a piece of sheet rubber in the centre of which is a button supporting a movable lever. The lever terminates in a fine point for writing on a revolving cylinder. Connected with this tambor by rubber tubing, is a second tambor like the first, excepting it has no lever. The button of the second is placed over the organ it is wished to examine. The movement of the latter is communicated to the air within the transmitting tambor, and the vibrations set up are carried through the connecting tube to the recording tambor, causing the lever to move.

Other recording instruments are the stethograph, plethysmograph, oncometer, and splenometer.

HYDRODYNAMICS.

CHAPTER XVI.

HYDROSTATICS.

Hydrodynamics deals with laws of force as applied to liquids, and comprises hydrostatics and hydrokinetics.

Hydrostatics deals with those laws regarding liquids at rest.

A **liquid** is a body with such slight cohesion, that a small force displaces its molecules relatively to one another. Owing to this easy displacement, liquids adapt their form to those of the containing vessels. Nevertheless, they are almost incompressible, but being elastic, return to their original volume upon removal of pressure. Gases, which are also fluid, differ from liquids in that their molecules vary in their distance from one another, being, therefore, expansible and altering their volume with every alteration of pressure.

Pascal's Law.—Pressure exerted anywhere upon a mass of liquid, is transmitted undiminished in all directions, and acts with the same force on all equal surfaces, and, in a direction at right angles to those surfaces.

Following this, the amount of force exerted upon any surface in a liquid under pressure, is proportional to its extent.

The **hydraulic press** embodies these principles.

Vertical Upward Pressure.—The pressure which the upper layers of a liquid exert on the lower layers, causes them to exert an equal reaction in an upward direction. This is termed the buoyancy of liquids. The upward pressure is governed by the same laws as the downward pressure.

Also in accordance with Pascal's law, is the fact that the pressure on the bottom of a vessel is independent of the shape of the vessel, and of the quantity of the liquid it contains, but is determined by the area of the bottom, and the height of the column of liquid it supports.

The Hydrostatic Paradox.—The pressure exerted must not be confounded with the pressure which the vessel itself exerts upon the body which supports it. The latter is always equal to the combined weight of the liquid and the vessel in which it is contained, while the former may be either smaller or greater than this weight according to the form of the vessel.

Equilibrium in several communicating vessels of the same liquid can be maintained only when the free surfaces of the liquid in all the vessels are in the same horizontal plane. The vessels may be of any given form. If there are two *different* liquids in communicating vessels, the height above the surface of contact will be in the reverse ratio of their densities.

The **circulation of the blood** is maintained according to these principles. Being a single fluid in a system of blood-vessels, the tendency is for it to distribute itself throughout the latter in an effort toward equilibrium. Opposed to this is the heart's action, and to meet it, a flow takes place to restore the previous condition, and so on, and as a result a continuous flow occurs.

Artesian wells exemplify the tendency of water to find its level.

When **a solid is immersed in a liquid,** every portion of its surface is submitted to a perpendicular pressure which increases with the depth. If the pressures be divided into horizontal and vertical, the first will be in equilibrium, while the latter will be unequal and tend to move the body upward. If a cube be immersed in a mass of water, the pressures on the perpendicular surfaces will be equal. The upper face will be pressed upon by a column of water whose height is the distance from the face to the surface of the water, and whose base is the face. The lower face will be be pressed upon by a column of water, whose base is the face itself, and whose height is the distance from the base to the surface of the water. The cube, therefore, is urged upward by a force equal to the difference between the two pressures, and this is equal to the weight of a column of water having the same base and the same height as the cube. The upward pressure is equal to the weight of the volume of water displaced by the immersed body.

Principle of Archimedes.—A body immersed in a liquid loses weight equal to that of the displaced liquid.

Equilibrium of Floating Bodies.—A body when floating, is acted on by two forces—its weight acting downward through its centre of gravity; and the force of the displaced liquid acting upward through its centre of gravity. In *stable equilibrium*, (a) the floating body must displace a volume of liquid whose weight equals that of the body; (b) the centre of gravity of the floating body must be in the same vertical line with that of the fluid displaced. If the floating body, being of irregular form, move to one side, the amount of liquid displaced will be different, and consequently its centre will be different. A vertical line drawn through the new centre and continued to meet the vertical drawn through the old centre, will at the point of intersection, give the *metacentre.*

The equilibrium of a floating body is stable or unstable according as the metacentre is above or below the centre of gravity.

Swimming.—The human body floats on the surface, because, as a whole, it is lighter than an equal volume of the water, especially sea water. The head being heavier than the lower portion of the body, tends to sink. The reverse is true of quadrupeds. Fishes move up or down in water by increasing or decreasing their volume.

The **specific gravity,** density or relative mass of a body is its weight as compared with the weight of the same volume of a body taken as a standard. The standard is water at a temperature of 4° C. The weight of the body divided by the weight of an equal volume gives the specific gravity. The principle of Archimedes is applied for this purpose, in the

Hydrostatic Balance.—The body is suspended from one of the pans of an ordinary scale and weighed. Under this pan, now, place a vessel of water, and allow the body to hang in it. It is pressed upward by the weight of the water displaced, and loses weight to that extent. The weight is again estimated, and is found to be equal to the weight in air less the weight of a quantity of water equal to its own volume. The first weight divided by the second, gives the specific gravity.

Hydrometers, for calculating specific gravity, are of two kinds: (1) of constant immersion but variable weight, and (2) of variable immersion but constant weight. To the first belong Nicholson's and Fahrenheit's.

Nicholson's hydrometer consists of a hollow metal cylinder made to float by the weight of an attached cone. At the top is a stem, on which is a mark, terminating in a pan. The apparatus is immersed in water, and weights are placed on the pan till the instrument sinks to the mark. The body whose specific gravity is to be obtained, is now placed on the pan, and the instrument sinks lower. Weights are removed till it stands at its former level. These weights give the weight of the body in air. The body is now transferred to the lower cone and the hydrometer rises, being lighter by an amount represented by the displaced water. The weights put on to sink the apparatus to the mark give the weight of the displaced water, which, divided into the weight in air, gives the specific gravity.

For measuring the specific gravity of liquids, the instrument is first placed in water and weighted down; then in the liquid. The weight required in the last step divided by that of the former gives the specific gravity.

Fahrenheit's hydrometer is better suited for this purpose. It is made of glass similar in form to Nicholson's, but the cylinder is continuous below with a small bulb containing mercury, for maintaining the vertical position.

Hydrometers of the second class consist of a glass tube with a bulb blown in the middle, and loaded at the bottom with mercury or shot. The stem has a scale marked upon it. The graduation of the instrument differs according as the liquid for which it is to be used, is heavier or lighter than water.

Salimeters are so constructed that when placed in distilled water, they sink nearly to the top of the stem which is marked 0. They are then placed in a solution of fifteen parts of salt to eighty-five of water, and the point to which they sink is marked 15. The distance between the two points is divided into fifteen equal parts and the graduation continued down the stem. For fluids lighter than water, the hydrometer is so loaded that in distilled water the surface is on a level with the bottom of the stem. In the *alcoholometer*, 0 is at this point, and the position to which the instrument sinks in pure alcohol, is marked 100.

Lactometers are similar instruments, graduated for specific gravities ranging from 1042 to 1014; 1033 to 1029 indicates good milk. Every fall of three points below this will indicate the addition of ten per cent. of water. A common plan of adulteration is the removal of cream from the milk which increases the specific gravity, and then the addition of water so as to restore the original weight. The lactometer will not reveal this fraud.

Urinometers sink in distilled water to the top of stem which is marked 1000. The graduation is continued down the stem to its bottom. The normal specific gravity varies from 1018 to 1025.

Specific gravity bulbs are often employed. They consist of hollow glass balls of varying weights, and are prepared in series. For urinary examination, six are used, graduated from 1005 to 1030. They may be placed in a tube, open at both top and bottom, which is plunged in the liquid. The specific gravity is determined by the number of bulbs floating.

CHAPTER XVII.

HYDROKINETICS.

Hydrokinetics deals with laws of force as applied to liquids in motion.

Torricelli's Principle.—The rate at which a fluid discharges itself (when falling freely through an opening in the thin wall of a reservoir) is equal to the velocity which would be acquired by a body falling freely through a height equal to the distance between the orifice and the surface of the liquid. The *velocity of efflux* is independent of the nature of the fluid. The *quantity discharged* in a unit of time ought to equal the velocity of efflux multiplied by the area of the orifice. It does not do so, because of the *vena contracta* which is a narrowing of the stream produced by opposing horizontal streams. It may be corrected by fitting to the orifice a small tube having the diameter of the orifice, and a length two or three times the diameter.

Mariotte's bottle consists of a glass reservoir with an outlet tube in one side near the lower part. The mouth is closed with a cork pierced by a tube which dips to a considerable extent, in the water. The object of the bottle is to maintain a uniform rate of flow without maintaining the supply. The bottle and tube being filled, the surface of the water bears a pressure equal to the atmospheric pressure and the weight of the water in the tube above the surface. If the water escapes from the tube to the level of the surface, then the latter will be at atmospheric pressure. The water is pressed out by a force equal to the atmospheric pressure and the weight of the liquid column whose weight is from the outlet to the surface; and is pressed in by the atmospheric pressure. If the water is allowed to escape until air bubbles begin to rise from the tube, then it is pressed out by the atmospheric pressure plus a column from the bottom of the tube to the orifice. This is constant so long as the level is above the end of the tube.

Liquids flowing through uniform tubes do not obey Torricelli's principle because of friction and resistance. Suppose a reservoir filled with water in communication with a horizontal tube through an opening at the lower part of the side, and uniform vertical tubes communicating at intervals with the horizontal tube, then (1) the rate of discharge is equal to the total discharge of the reservoir, less the force required to overcome the resistance; (2) the resistance is directly proportional to the length of the tube; (3) the resistance increases with the speed of the stream; (4) the resistance is in inverse proportion to the diameter of the tube; (5) the resistance increases with the force of cohesion of the liquid.

Flow Through Tubes of Varying Diameter.—When a small tube passes suddenly into one of larger diameter, there is a sudden increase of pressure at the junction and a diminution of speed in the wide tube. Increased force is developed because the molecules cannot, quickly enough, change the swift movement into a slower one. Where a wide tube enters into a narrow one, there is a diminution of pressure.

Bending of the tube produces increased resistance behind the bend, decreased resistance in front of it, diminished amount of current, but speedier advance. As a whole, the pressure and speed of movement are unaffected.

In a **ramified system** of tubes, friction is increased by (1) an increased surface of tubes, and (2) angles and bends. Opposed to it is the increase of calibre allowing easier flow. Where a trunk is formed, resistance is increased by (1) the meeting of currents, and (2) the angles of junction. Opposed to it, is the increased speed of a diminished current in front.

Flow Through Elastic Tubes.—This may have the same characteristics as when liquids pass through rigid tubes; e. g., there may be a constant flow under a constant pressure which either does not distend the tube beyond its normal calibre, or distends it to the utmost. Elasticity is manifested only when the equilibrium is disturbed. A volume of liquid is pressed into the tube and it dilates, only to recoil when the pressure is withdrawn, and send the fluid to the next portion which behaves in a similar manner, and so on. A wave is thus sent onward, travelling on the surface of the current. In an elastic tube with no current, it may exist alone, or if the tube be open at one end, they can co-exist and in the same or opposite directions, in the former instance being a *positive* wave, in the latter a *negative* wave. The *extent of the wave* depends upon the suddenness of the disturbance of equilibrium, and the quantity of fluid injected.

The *speed of propagation* depends upon the elasticity of the tube, the rapidity of impulses and the density of the fluid. The *height* of the wave depends upon extensibility of the tube, being directly proportional to it, while the *length*, also so dependent, is inversely proportional to it.

Comparing Rigid and Elastic Tubes.—If both be filled with fluid and under the influence of the same intermittent force, injection of more fluid into the former, will result in an outflow of an equal amount, and in the same manner. In the latter, there will be dilatation, followed, when the force has passed away, by recoil, dilatation of the next portion, recoil, etc. The reaction acts only in the intervals between the action of the intermittent force, resulting finally in the transformation of an intermittent into a continuous flow. Elastic tubes diminish the velocity of the current, but increase the quantity of fluid discharged. The reverse is true of rigid tubes.

CHAPTER XVIII.

DYNAMICS OF THE CIRCULATION.

Blood circulation occurs in three sets of vessels. (1) The *arteries* (whose beginning is the aorta which arises from the heart), divide and subdivide, becoming constantly smaller, and pass into (2) the *capillaries*, which are of microscopic size and wide-spread distribution. These give rise to (3) the *veins*, which at first small, later form two large vessels whose office is to convey the blood to the right side of the heart. The total calibre of the vessels increases from the aorta to the capillaries, and diminishes from the latter to the veins.

The force of the heart is expended (1) to overcome resistance due to friction of the blood against the vessel walls, and (2) to produce a certain rate of flow.

Blood pressure is the force exerted by the blood upon the vessel walls, and is due to the heart's action. *Arterial tension* is the force exerted by the vessel walls upon the blood, and is due to the elastic recoil of the vessels. *Pressure* does not lessen regularly from the heart onward, because the vessels are of varying diameter. It diminishes slowly in the arteries, very rapidly in the capillaries, and again slowly in the veins where it is least.

The **velocity of flow** diminishes from the aorta to the capillaries, and increases from the latter to the right side of the heart, but at the latter it is not as great as in the aorta.

The **pulse** is due to dilatation of an artery caused by sudden injection of blood, and the recoil of the walls upon the enclosed blood. It is a wave, and must not be confounded with the onward movement of the blood itself. *Tracings of the pulse* are obtained by sphygmographs. *Characteristics:* (1) The *upstroke* indicates the more or less sudden injection of blood into the artery, being abrupt or oblique, respectively; (2) the *summit of the curve* indicates the period of greatest tension of the arterial wall; (3) the *downstroke* indicates the diminution of arterial tension. A pulse tracing of *high tension* is low and long, and indicates that the vessel is very much distended or extensible with difficulty. One of *low tension* is high and short, indicating that but little force is being exerted by the vessel. Very often, in the downstroke, is seen a secondary rise or *dicrotic* wave due to a rebound of the blood from the sigmoid valves, and rendered more prominent by the small volume of an injection, and by considerable elasticity of the arterial wall with feeble tension.

Blood pressure is estimated by the **manometer** which consists simply of a U-shaped tube, one end of which is in communication with an artery. The tube is filled with mercury, a solution of bicarbonate of sodium being between it and the blood to prevent coagulation. The readings are taken (by means of a scale attached to each limb of the tube) of the difference of level of surfaces in the two limbs.

The **kymographion** is similar to the manometer, but has in its free end a float with an arm that impinges against a revolving cylinder.

The *spring kymographion* was devised to overcome the objections due to the mercurial inertia of the other instruments. It consists of a hollow spring, C-shaped (which is filled with alcohol), whose lower end communicates with a lead tube which is filled with bicarbonate of sodium, and connected with a T-shaped tube in the blood-vessel. The other extremity is closed, and has a lever which projects against a revolving cylinder.

The **cardiograph** is a modification of the tambor, used for obtaining tracings of the cardiac movements.

The **stromuhr** is an apparatus for determining the speed of the blood stream. It consists of two glass vessels connected above by an arch surmounted by a metal cap. The vessels are supported on a metal plate which is capable of revolving on a metal support. Passing through the plate and support on each side from the vessels, is a tube ending in canules which are to be inserted into the cut ends of a blood vessel. One vessel is filled with defibrinated blood, the other with pure olive oil. When the speed of the stream is to be obtained, the stromuhr is connected with the artery so that the flask containing the blood is in communication with the distal end. The blood entering the apparatus, forces the oil from the vessel containing it, to the other, this, in turn, forcing the defibrinated blood into the circulation. The apparatus is then quickly rotated, and the manœuvre repeated. The number of turns is noted, and as the time taken and the capacity of the flasks are known, the quantity of blood passing in a given time can be calculated.

The **sphygmograph** is for the purpose of recording variations in the pulse. In *Marey's*, an ivory button is made to rest lightly on the artery, the pulsations of which it is desired to investigate. The up-and-down movement of the button is communicated to a lever, to the hinder end of which is attached a slight spring, which allows the lever to move up, at the same time being strong enough to resist its making any sudden jerk, and in the interval of the beats, also assisting in bringing it back to its original position. The up-and-down movement of the lever is recorded on a smoked card which is made to move by clockwork.

A more accurate instrument is the **sphygmometer** of Roy and Adami, which consists of a box moulded to fit over the end of the radius so as to bridge the radial artery. Within it, is a flexible bag filled with water, connected by a T-tube with a rubber bag and mercurial manometer. The fluid in the box may be raised to any desired pressure, and be then shut off by a tap. At the upper part of the box, is a circular opening; and resting upon the flexible bag is a flat button, which, by means of a short, light rod, communicates the movement of the flexible bag to a lever. To the axis of rotation of the lever, is attached a spiral watch-spring which can be tightened at will, so that the lever can be made to take a vertical position at any desired hydrostatic pressure within the box. The movements of the lever are recorded upon a piece of blackened, glazed paper made to move in a vertical direction past it. When in use, the box is fixed upon the end of the radius by a holder, and the pressure is raised to any desired height to which the lever is adapted, by tightening or slackening the spring. The tap is then closed. The pressure within the box acts in all directions, and is correctly indicated by the manometer.

CHAPTER XIX.

CAPILLARITY.

Cohesion is the attraction existing between molecules of the same body. It is greatest in solids, less in liquids, and least in gases.

Surface Tension.—The free surface of a liquid has greater cohesion than any other. If the attractive forces of the adjacent molecules be resolved into horizontal and vertical parts, the former will compensate each other; but the attractions of the latter are not so exerted, and there is a considerable pull toward the interior. This is called surface tension.

Cohesion in liquids is seen in the rounded form of a drop of water falling freely; or a globule of mercury on a plate of glass or wood.

Adhesion is the attraction existing between the molecules of different bodies in contact. It is seen whenever a liquid wets a body.

Capillary Attraction.—(1) If a tube of very small bore be plunged into a liquid that wets it, the liquid will rise in the tube above the level of the surface of the surrouding liquid, and its surface will present a depression called the *concave meniscus.* Here, adhesion overcomes cohesion. The liquid molecules are sustained in equilibrium by the forces acting on them, and they exert no downward pressure on the inferior layers. On the contrary, in virtue of molecular attraction, they act on the nearest inferior layers, from which it follows that the pressure on any layer in the interior of the tube, is less than if there were no meniscus. The consequence is that the liquid rises in the tube until the internal pressure on the layer is equal to the pressure which acts externally on a point of the same layer. The height of the column is inversely proportional to the diameter of the tube, and to the temperature. (2) If the tube be plunged into a liquid that does not wet it, instead of an ascent, there will be a depression, and the surface of the column will be convex. This is called the *convex meniscus*, and is due to cohesion overcoming adhesion. Equilibrium exists in virtue of the molecular forces acting on the liquid. The surface tension is increased, but if permitted to remain, there would be increased pressure within the tube which is contrary to Pascal's law. Therefore, the liquid falls till its surface is so far below that of the outer liquid, that the column of liquid representing the difference would exert a pressure equal to the increased pressure produced within. (3) If two parallel plates at a short distance apart, are immersed in a liquid that wets them, the latter will rise between the two plates in the inverse ratio of the separating distance. If the liquid does not wet them, a corresponding depression is produced. (4) If a conical glass tube contain liquid that wets it, the latter will have a concave meniscus at each end, and will tend to move towards the vertex. The reverse holds with a liquid that does not wet the tube.

Imbibition.—Bodies that "soak up" fluids may be considered as possessing tubes that exert capillary attraction upon the liquids in which they are plunged. They are porous, and hold the fluid after they have been withdrawn from it. This is imbibition. The various tissues of the body absorb fluids in virtue of this property; and are thus enabled to perform their functions. The extent of imbibit on depends both upon the tissue and upon the liquid which moistens it.

CHAPTER XX.

DIFFUSION, OSMOSIS, ETC.

Diffusion, or mixing of different fluids, can occur only when adhesion overcomes cohesion; as in the case of alcohol and water. If the force of cohesion is the stronger, diffusion does not occur, as in the case of oil and water. A solid substance dissolves in a liquid when the adhesive force is greater. But there comes a time when the liquid is unable to overcome further the cohesive power of the solid. The *point of saturation* is reached. It varies with the solid, and the liquid dissolving it.

Laws of Diffusion.—(1) When solutions of the same sub stance, but of different strengths, are taken, the quantities diffused in equal times are proportional to the strengths of the solutions. (2) If the solutions contain equal weights of different substances, the quantities diffused vary with the nature of the substances. (3) The quantity diffused varies with the temperature, increasing with its rise. (4) If two substances which do not combine, be mixed in solution, they may be partially separated by diffusion, the more diffusive one passing out more rapidly. In some cases, even chemical decomposition may be effected. Thus, bisulphate of potassium is decomposed into free sulphuric acid and neutral sulphate of potassium. (5) If liquids be dilute, a substance will diffuse into water containing another substance dissolved, as into pure water; but the rate is materially reduced if a portion of the same diffusing substance be already present.

Albumen which has a very low rate of diffusion, does not impair the diffusion of salts dissolved together with it in the same solution, although the liquid retains its viscosity.

Osmosis is the passage of liquids through a membrane due to the affinity of at least one of the liquids for the membrane.

The **osmometer** consists of a vessel open at the bottom, tied round with a bladder. In the neck, a long, narrow tube is inserted. Down it is poured the solution, and the instrument is immersed in a vessel containing distilled water.

Conditions Necessary for Osmosis.—(1) The two liquids must be miscible. (2) At least one must be capable of permeating the membrane. (3) Increase of volume usually occurs on the side of the fluid of greater density. The mixture of dissimilar liquids can be carried on when the change of volume is forcibly prevented.

Endosmosis is the passage into the osmometer of a current. *Exosmosis* is the passage out of the osmometer of a current.

Influence of Capillarity.—The separating membrane contains a large number of capillary tubes in which some liquids will ascend higher than others. Endosmosis is explained to be due to the unequal affinity of two different liquids for the same membrane. The endosmotic current having more affinity, will have risen in the tubes a considerable distance, before it meets the stream passing in the opposite direction; diffusion will occur in the pores, and a new supply will rise and push the mixture out on the side of less affinity. Exosmosis is due to simple diffusion, the liquids being in contact in the tubes, and independent of any aqueous current.

Conditions Influencing Osmosis.—(1) The degree of concentration, within certain limits. (2) The nature of the solutions employed affect osmosis by affecting the membrane. Water will pass more readily through an animal membrane, than will alcohol, the latter contracting the pores. (3) Osmosis will occur between two solutions of the same nature, but of different densities. The action will be hastened by maintaining the concentration of one of the solutions, especially if the dilute solution be made to flow past the membrane. (4) When the two solutions differ chemically, the action will be influenced by their chemical affinity. (5) If a constant electrical current be arranged so that the positive pole is on one side of the membrane, and the negative pole on the other, the direction of osmosis will be toward the latter. Under these circumstances, substances which are not ordinarily permeable, may be made to pass through membranes. Thus, cataphoresis is explained.

Crystalloids are substances capable of diffusing through membranes, and of assuming crystalline forms.

Colloids are substances of very low diffusibility, characterized by their incapacity for taking crystalline form, by the mucilaginous character of their hydroxides, their inertness in ordinary chemical relations, and their mutability. While themselves of extremely low diffusive power, they afford a medium of diffusion.

Dialysis is the separation of crystalloids from colloids effected by an apparatus called a dialyzer. This consists of a ring of guttapercha over which is stretched, while wet, a sheet of parchment paper forming thus a vessel about two inches high and ten inches in diameter. After pouring in the solution to be dialyzed, the whole is floated on a vessel containing a very large quantity of water. In the course of one or two days, a more or less complete separation will have been effected. Thus, a solution of arsenious acid mixed with various colloids, readily diffuses out.

Endosmotic equivalent is the term applied to the weight of distilled water that passes into the flask of the osmometer, in exchange for a known weight of the soluble substance that escapes from it. It is not constant for each substance, and is influenced by (1) the temperature, which, as it increases, generally increases the endosmotic equivalent; (2) the degree of concentration of the solutions, being greater for dilute solutions; and (3) the porosity of the membrane.

Mechanism of Absorption.—The conditions present for osmosis in the human economy are (1) the presence of a membrane formed by the walls of the blood vessels, stomach and intestines, separating the contents of the stomach and intestines from that of the blood vessels. (2) The blood is an albuminous, or colloid, substance, and therefore, does not ordinarily penetrate the membrane. On the other hand, those alimentary substances not crystalloids, are converted into them by the digestive ferments, and can permeate the vessel walls. (3) The presence of hydrochloric acid in the stomach interferes with the passage of blood outward into the stomach. (4) The constant and rapid passage of blood past the membrane facilitates the endosmotic current. (5) The great extent of the membrane also predisposes to it, as does (6) the difference in composition or concentration of the two fluids.

Catharsis and Diuresis.—(1) If a concentrated solution of magnesium or sodium sulphate, these having a high endosmotic equivalent, is introduced into the intestines, diarrhœa will follow. (2) If the solution taken in by the mouth, contains as much saline matter as the blood, a sense of fulness is soon experienced, because absorption is slow. (3) Finally, if a very dilute solution is drunk in large quantities, there soon follow copious evacuations of the urine.

Absorption by other tissues and structures, as the lymphatics and villi, serous membranes, etc., follows the rules laid down for the stomach and intestines. As hydrochloric acid hinders the flow outward, so substances taken in with food, though not interfering with digestion, may retard absorption and give rise to symptoms of indigestion. Fat is such a substance. Its absorption is due to a vital power of the intestinal epithelium. This latter property, probably more than osmosis, enters into the process of secretion.

Filtration is the passage of fluids (rarely solids) through the coarse intermolecular pores of a membrane, owing to pressure. *Conditions influencing.*—(1) The rate is increased by (a) increase of pressure, (b) increased size and number of the pores. (2) Substances imbibed by the membrane filter most rapidly. (3) The filter may retain either the substances in solution, or water; the filtrate, in the first instance, being more dilute, in the second, more concentrated than the original solution. (4) The surface of the membrane next the solution. The shell-membrane of an egg permits filtration only from without inward. (5) In a mixture of crystalloids and colloids, the presence of the former retards the speed of filtration of the latter. The change is quantitative.

Filtration occurs normally in the body in the excretion of the watery portion of the urine. Dropsy is due to an *abnormal* filtration produced by an increase of venous pressure.

CHAPTER XXI.
PNEUMATICS.

Properties of Gases.—Gases are fluids and possess those properties which belong to other fluids and liquids. Their particles are mobile, which permits of easy movement in air. They transmit pressure equally in all directions, like liquids, but are both more elastic and compressible than the latter.

The *expansibility of gases* is due to the repulsive action exercised between their molecules. They not only may be displaced, but the displacement is not relative, as in the case of liquids. Because of this elacticity, gases have no volume and tend to fill whatever space may contain them, exerting at the same time, pressure upon the container.

The *compressibility of gases* is due to the extreme mobility of their molecules. While liquids are compressible to a slight extent only, developing a very great reactive force, gases are readily compressible, and may be reduced to half their volume without developing a force greater than that of the atmosphere.

Boyle-Marriotte Law.—The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure it bears. Briefly, the pressure is inversely proportional to the volume, and directly proportional to the density.

The law is only approximately true, some gases diminishing in volume more rapidly than air; while hydrogen, which has the same compressibility up to 15 atmospheres, is then less compressible.

That *gases have weight* can be demonstrated by weighing a globe containing no air, suspended from one pan of a balance. Upon allowing the entrance of a gas, the balance is depressed on the side of the globe.

Gases have density in common with other fluids, though in much less degree. The principle of Archimedes holds regarding them. The weight of a body in air is the difference between its true weight and the weight of the displaced volume of air.

Atmospheric Pressure.—The height of the atmosphere has been variously estimated at from 30 to 212 miles. The density diminishes from the earth upward, the lowest layers, those next to the earth, being most dense because sustaining the pressure of all the layers above them. If the density were uniform, a layer of air about five miles thick, encircling the earth, would give a pressure equal to the ordinary atmospheric pressure. This height is called the *height of the homogeneous atmosphere.* On a square inch of the earth's surface, the pressure is about 14.7 pounds. Place over the orifice in the plate of an air pump, a cylinder, one end of which is covered by a piece of rubber membrane. Exhaust the air, and the membrane will be sucked inward and finally burst because of the crushing force of the atmosphere.

Torricelli's experiment has for its object the measurement of atmospheric pressure by the height of a column of liquid which it supports. A tube three feet long and a quarter of an inch internal diameter, closed at one end, is completely filled with mercury. The open end is closed by the thumb, the tube inverted in a vessel containing mercury, and the thumb removed. The tube being in a vertical position, the column of mercury sinks, and, after oscillating some time, finally comes to a rest at a height which, at the level of the sea, is about thirty inches (760 mm.) above the mercury in the vessel. The space above the mercury is called the Torricellian vacuum. If the weight of the atmosphere diminishes, as when ascending a mountain, the height of the column diminishes. At the same place, the column will stand higher with a high than with a low, temperature, the density, though not the pressure, varying. The pressure of a column of mercury 30 inches high, and at 32° F., is called the *pressure of one atmosphere.*

Barometers are instruments used for measuring atmospheric pressure. The simplest form is that described in the Torricellian experiment. The mercury must be boiled to get rid of air and vapor which would interfere with the production of a vacuum. Various forms of barometers in use are the syphon, cistern, wheel and aneroid.

Effects of Atmospheric Pressure.—The pressure of the atmosphere will support a column of water 34 feet high, in a tube exhausted of air. This gives a means of raising water from a low to a higher level, the water continuing to rise till it produces a downward pressure equal to the upward pressure of the atmosphere.

The *suction-pump* is based on this principle. It consists of a cylinder at the bottom of which is a valve opening upward; of a suction-tube whose lower extremity dips into the reservoir, and whose upper extremity is in communication with the cylinder; and of a piston with an orifice closed by a valve opening upward. When the piston is raised, a vacuum is produced in the cylinder; the piston valve is closed by atmospheric pressure, the cylinder valve is opened, and air from the pipe passes in. The piston descending, the cylinder valve closes, while the piston valve opens and permits the escape of the air. At the next upstroke, water passes into the cylinder; and when the piston comes down, pours through the orifice in the piston, to be lifted out by the succeeding rise of the piston.

The *suction- and force-pump* depends both on exhaustion and pressure. The cylinder has a valve in connection with the suction tube, and another, opening in the same direction, closes a conduit which passes from a hole near the first valve into an air-chamber. From this, there passes another tube up which the water is forced.

The *pipette* consists of a tube pointed at one extremity, and with a bulb blown about its centre. Air is exhausted by sucking with the mouth or a rubber bulb, and the tube is filled with the fluid it is desired to raise.

The *syphon* is a bent tube, open at both ends, and with unequal legs. Used to transfer liquids, it is first filled in some manner, and the two ends being closed, the short end is dipped into the liquid which will run out as long as this end is immersed. The liquid is pressed up the short leg by the atmospheric pressure less the weight of the column in the leg; and is pressed down the long leg by the weight of the atmosphere less the pressure in the long leg. But as this column is longer than the other, the force acting at its outlet is less than the force acting at the inlet, and consequently, a flow occurs proportional to the difference between the two forces.

The *aspirator*, used for withdrawing fluids from abscesses, etc., consists of a hollow steel needle, sharpened at one end, and in connection with an air-tight cylinder at the other end. To use, the piston is shoved home, the needle inserted; and the piston then being withdrawn, a vacuum is produced, the fluid running in as a consequence.

Atomizers depend for action upon increase of pressure which is furnished by compressing a bulb fitted on to a projection of a tube. Air is forced through, presses upon the liquid in the flask, which in consequence, rises in a second tube sealed within the first one. The external orifice has a diameter much smaller than that of the tube itself, and, therefore, the stream is broken up into a spray at its exit.

Cupping instruments consist of vessels which are exhausted of air by compression or aspiration. Applied to the skin after exhaustion is accomplished, the tissues rise in them filled with blood. If it is desired to "wet cup," the skin is first scarified. A simple method of cupping is to pour spirit in an ordinary glass, and light it. The air is thus rarified, and the effects above noted are produced when the glass is applied to the skin.

The **air-pump** is an apparatus by means of which the air in any enclosed space may be rarified, and the atmospheric pressure diminished. It consists of a strong base at one end of which is a round and perfectly level glass or metal plate pierced at its centre by a hole which communicates with a tube. The jar to be exhausted is placed on the plate with its edges well greased. The other end of the tube communicates with a barrel in which there works up and down, by means of a lever, an air-tight piston. The piston is pierced by a hole which is covered by a valve opening upward. When the piston is raised, its valve closes and air passes from the jar (receiver) into the cylinder. In descending, the valve opens, the air escaping outward into the atmosphere. To prevent air passing into the receiver on descent of the piston, there is a valve which opens and closes the orifice of the tube in connection with the receiver. It is fixed to the end of a rod which moves, but with friction, through the piston. When the piston sinks it carries with it the rod, and closes the orifice. As the piston rises, it lifts the rod, but only for a small distance, for the rod stikes against the top of the barrel, and the piston, continuing its upward motion, slides along the rod.

As rarefaction proceeds, it becomes more difficult to work the pump, atmospheric pressure greatly exceeding the pressure in the receiver. It is easily perceived that a perfect vacuum is never obtained, for each stroke of the piston extracts only a portion of the air in the receiver which continually expands to occupy the space formerly occupied by the air withdrawn.

Sprengel's air-pump, which produces a more perfect vacuum than the one described before, is based upon the Torricellian experiment. It consists of a glass tube longer than a barometer, open at both ends, and connected by means of rubber tubing with a funnel which is filled with mercury and supported by a stand. The falling of the mercury in the tube is regulated by a clamp on the tubing below it. The lower end of the glass tube fits in a flask which has a spout a little higher than the orifice of the tube. The upper part has a branch to which a receiver can be tightly fixed. When the clamp is opened, the first portions of mercury running out close the tube and prevent the entrance of air below. As the mercury falls, exhaustion goes on, and the tube, from the receiver branch to the level of the mercury in the flask, is filled with cylinders of liquid and air having a downward motion. Escape is made through the spout of the flask, the mercury being caught in a basin below it, and later, poured back in the funnel to be repassed until exhaustion is complete. As this stage is reached, the columns of air between those of mercury, are seen to diminish, until in the lower part of the tube is formed a column of mercury about 30 inches high. At this time, the liquid falls with a dull, metallic sound. Exhaustion is completed when all air has disappeared, and a drop of mercury falls in the column without carrying with it the least trace of air. This apparatus is used for exhausting Geissler's tubes, Crookes' tubes, and incandescent electric lamps.

Physiological Effects of Atmospheric Pressure.—(1) Contained in the chest are the lungs (which communicate with the outside air by means of the bronchi) and the heart. The cavity of the chest is air-tight, and the lungs are always in contact with its walls unless perforation from the outside occurs, when the lungs immediately fall away from the thoracic walls. Although the intra-thoracic never quite equals the extra-thoracic, pressure, practically, we may say that equilibrium exists at certain periods of the respiratory cycle. When respiration occurs, this equilibrium is disturbed. In inspiration, the cavity of the chest is enlarged, and there is a fall of pressure until air rushes in and fills the lungs; and equilibrium is restored. The muscular action, necessary for the enlargement of the chest, ceasing, recoil occurs, brings about increase of the intra-thoracic pressure with reduction of the volume of the lungs, and again equilibrium is restored, until inspiration follows, and the cycle described is repeated.

(2) *On the Circulation.*—(a) The fall of pressure produced

by inspiration, causes a dilatation of the large veins entering the heart. This brings about a momentary fall of pressure, to be followed, however, by increase of flow as soon as the inertia of the blood is overcome by the suction. Upon the arteries within the chest, no such effect is produced, for the aspiration has not the strength to overcome the elastic coats of the arteries; so that inspiration aids the circulation. Tracings show that the acme of inspiration does not correspond with the acme of circulation, for, as remarked, there is an evanescent fall of blood pressure at the beginning of the inspiration. (b) In expiration by which the intra-thoracic pressure is increased, compression of the veins retards the flow within them; but the same force acting on the arteries, increases the flow within them, so that as a whole, there is neither decrease or increase.

(3) As one ascends from the sea level, atmospheric pressure becomes reduced, manifesting itself in various directions. There are increased rapidity of respiration and of the heart, followed if the ascent be continued, by fatigue, dyspnea, and possibly asphyxia; congestion of the capillaries of the skin and mucous membranes which may culminate in hemorrhage, and does lead to sweating and free mucous secretion; vomiting; diminished secretion of the urine; and various nervous symptoms.

(4) Descending below the sea level, the skin becomes pale and perspiration diminishes. The respirations are reduced in frequency, inspiration is accomplished more easily, expiration is prolonged, and a distinct pause occurs between the two acts. Urinary secretion is increased; and muscular efforts are made with more strength and activity. The heart beats slower, and there is a sensation of warmth.

(5) At sea level, the pressure of 14.7 pounds per square inch is not felt for it is exerted equally upon all surfaces of the body.

(6) Atmospheric pressure plays a part in keeping in close apposition the various joints of the body, especially the hip and shoulder joints.

CHAPTER XXII.

GASEOUS DIFFUSION AND ABSORPTION.

Mixture of Gases.—If two flasks containing gases be connected, the gases will at once begin to mix regardless of their density; and in a varying length of time, the mixture will be completed unless chemical action occurs. This is due to the elastic force of gas. If the flasks contain the same kind of gas at the same temperature and pressure, diffusion will not occur; but if they be at different temperatures and pressures, mixture takes place as if they were diffusing into empty space, but with lessened speed.

Henry-Dalton Law.—The pressure exerted by a mixture of gases equals the sum of pressures exerted by the gases severally. Each gas, i. e., exerts its individual pressure independent of the other gases present, and this pressure is called the *partial pressure* of each gas in the mixture.

Physiology.—The vital capacity of the chest is 225 cubic inches, while only 30 cubic inches of air, composed of a mixture of O, CO_2, and N, are drawn with each inspiration, into the air passages and lungs which already contain the same gases, but in different proportions. Owing to the expansibility of gases and their power of diffusion, the quantity inspired will come to occupy the lungs. Proceeding from the upper to the lower parts of the lungs, it is found that the amount of O constantly decreases while the amount of CO_2 increases. By diffusion, then, and obeying the Henry-Dalton law, the incoming air loses O and takes up CO_2 until the mixture is homogeneous. The rate remains uniform, for although the inspired air is continually being deprived of O, the quantity of this gas is found to gradually lessen in the previously contained air, as the vesicles are reached. The amount of CO_2 in the inspired air is always less than that in the lungs; and diffusion goes on between them also, until there is equilibrium.

Gaseous Diffusion Through Porous Diaphragms.—Gases osmose in a manner similar to liquids. When two different gases are separated by a porous diaphragm, an interchange takes place between them, the composition of the gas on either side of the diaphragm becoming ultimately the same. The rate of the interchange depends on the density of the gases, being inversely as their square root. The apparatus used consists of a glass tube about twelve inches long and closed at one end by a plug of dry plaster-of-Paris. If filled with hydrogen, and the open end immersed in mercury, diffusion of the gas will take place so rapidly that a partial vacuum is produced, and mercury rises several inches in the tube. Better, however, take two vessels of equal capacity, one containing oxygen and the other hydrogen separated by a porous septum. Diffusion occurs; and after a time it will be found that for every part of oxygen that has passed into the hydrogen, four parts of hydrogen have passed into the oxygen. If unequal mixtures of CO_2 and O be separated by the diaphragm, diffusion will go on between them until the mixtures are homogeneous.

Absorption of Gases by Liquids.—Gases are absorbed to a greater or less extent by water and other liquids, the amount absorbed being dependent upon (1) pressure and (2) temperature. The weight of gas taken up is directly proportional to the temperature, an increase of pressure and decrease of temperature causing the liquid to take up more of it; while decrease of pressure and increase of temperature have the reverse effect. Those gases which are liquefied most readily are absorbed in greater amount. The *coefficient of absorption*, or solubility of a gas also plays an important part in determining the amount of gas a liquid will absorb. It is the volume of the gas absorbed by a unit volume of the liquid at 0° C. and 760 mm. pressure. (3) The quantity of gas which a liquid can dissolve is independent of the nature and of the quantity of the other gases which it may already hold in solution; and conversely, according to what is called the *condition of equal tensions*, if a liquid containing a gas in solution be exposed to an atmosphere containing none of the gas, the gas will be given up to the atmosphere until the amount in the liquid and in the atmosphere become equal. The amount of gas absorbed or given off depends upon the partial pressure of that gas. For instance, oxygen forms only about one-fifth the quantity of air; and water exposed to air, under ordinary conditions, absorbs only such a quantity of oxygen as it would do if the atmosphere were entirely formed of this gas under a pressure equal to one-fifth that of the atmosphere.

Physiology.—In the lungs, separated by a membrane, as it were, made up by the very thin walls of the alveoli of the lungs and of the pulmonary capillaries, there is on one side a mixture of O, CO_2 and N, and on the other the blood containing these gases in different proportion. The blood contains an excessive amount of CO_2 and a diminished amount of O as compared with the mixture in the alveoli; and, in accordance with the Henry-Dalton law, CO_2 should leave the blood; and O, the pulmonary air until there results a condition of equal tensions. This does not occur because, in the first place, all of the CO_2 does not exist simply dissolved in the blood, but in chemical combination. That which is absorbed is given up according to the law, but to effect the escape of the remainder, the addition of an acid is necessary. It is thus thought to be in combination with some material of the blood-plasma, probably sodium carbonate. Exposure of the blood to the mercurial pump will extract nearly the whole of its CO_2. Neither does the oxygen of the blood obey the law of pressure. If blood containing little or no oxygen be exposed to a succession of atmospheres containing more and more of that gas, absorption is, at first, very great, but soon becomes relatively small, not being, therefore, regularly in proportion to the increasing amount of the oxygen. If arterial blood be submitted to regularly decreasing pressures of oxygen, at first very little of the contained gas is given off, then suddenly, the gas escapes with great rapidity, and again disobeys the law of pressures. Very little oxygen can be obtained from plasma freed from blood corpuscles, even by the strongest mercurial pump; neither can it be made to absorb a large quantity of that gas; but the small quantity which is so given up or absorbed, follows the law of absorption according to pressure, and this small quantity exists simply dissolved in the plasma. Hemoglobin is the chief solid constituent of the red corpuscles, and it is found that it absorbs oxygen to a certain extent under favorable conditions, and gives it up when subjected to the action of reducing agents, or to a sufficiently low oxygen pressure. From these facts, it is inferred that the oxygen of the blood is combined with the hemoglobin, but loosely; and not simply dissolved in the plasma.

OPTICS.

CHAPTER XXIII.

NATURE, VELOCITY, ETC., OF LIGHT.

Theories of Light.—Light is the agent which, by its action on the retina, excites the sensation of vision. That part of physics dealing with its properties is called *optics*. (1) The *emission* theory of light assumes that luminous bodies emit, in all directions, an imponderable substance composed of very subtle molecules, (propagated in straight lines with an almost infinite velocity) which, penetrating the eye, act on the retina and give rise to the sensation of light. (2) The *undulatory* theory supposes that all bodies and spaces are filled with an extremely tenuous medium called *luminiferous* or *universal ether*, and that the luminosity of a body is due to an infinitely rapid vibratory motion of its molecules, which when communicated to the ether, is propagated in all directions in the form of spherical waves, and this vibratory motion, transmitted to the retina, calls forth the sensation of vision. The vibrations are transverse to the direction of the waves. There is no progressive motion of the particles themselves, but only of the state of disturbance communicated by the luminous body. That the atmosphere is not necessary for the transmission of light, is proved by the fact that a luminous body does not become invisible in a vacuum. The *period of vibration* is the time occupied by one of the particles from the moment it leaves one position to the moment it returns to the same position in the same direction. The *phase of vibration* is the position occupied by a particle. The *amplitude of vibration* is the distance from the middle of a wave to one of its extremes. The *frequency of vibration* depends upon the number of vibrations per second. It is related to the period. The *wave length* is the distance through which the change of form has been propagated during the complete period of vibration of a particle. The *intensity* of light depends upon the amplitude of vibrations; while *color* will be found to depend upon the frequency of vibrations.

Luminous bodies are those which are in a state of vibration to emit light. *Transparent* or *diaphanous* bodies are those which readily transmit light, and through which objects can be distinguished. *Translucent* bodies transmit light, but objects cannot be distinguished through them. *Opaque* bodies do not transmit light. No bodies are absolutely opaque, all being more or less translucent when cut in sufficiently thin leaves.

A *luminous* ray is the direction of the line in which light is propagated. A *luminous pencil* is a collection of rays from the same source, and is said to be *parallel* when composed of parallel rays; and *divergent* or *convergent* when the rays separate from each other, or tend to the same point, respectively.

In every *homogeneous* medium, light is propagated in a straight line.

When light falls upon an opaque body, it cannot penetrate into the space immediately behind it, and this space is called the *shadow*.

The *velocity of light* is 186,000 miles per second in air. It decreases when passing through denser media.

Images Produced by Small Apertures.—Luminous rays, passing into a dark chamber through a *small* aperture, and falling upon a screen, form inverted images of external objects, whose shapes are always those of the objects, and independent of the shape of the aperture. The phenomenon is due to the rectilinear propagation of the rays which cross one another in passing through the aperture. The smaller the aperture, the more acute is the image.

The intensity of illumination on a given surface, is inversely as the square of its distance from the source of light.

CHAPTER XXIV.

REFLECTION OF LIGHT.

Laws.—(1) The angle of incidence is equal to the angle of reflection. (2) The incident and the reflected rays are in the same plane, which is perpendicular to the reflecting surface.

Mirrors are bodies with polished surfaces which, by reflection, show objects presented to them. They may be plane or curved.

Plane mirrors produce images of the same form and size as the objects, which seem to be situated the same distance behind, as the object is in front. The image, further, is reversed. Metal mirrors which have but one reflecting surface, give only one image. Glass mirrors give rise to many images. When an object is placed between two plane mirrors, which form an angle with each other, either right or acute, images of the object are formed, the number of which increases with the inclination of the mirrors.

Spherical mirrors are those which form part of the surface of a hollow sphere. According as the reflection occurs from the internal or from the external surface, it is said to be concave or convex. The centre of the sphere, of which the mirror forms part, is called the *centre of curvature*. The distance between it and the surface of the mirror is the *radius of curvature*. *The centre of the figure* is a point in the surface equi-distant from all parts of the circumference; and a line joining this with the centre of curvature is the *principal axis* of the mirror. Any straight line passing through the centre of curvature, but not the centre of figure is a *secondary* *axis*. The angle formed by joining the centre of curvature and extremities of the mirror is the *aperture*. The *focus* is a point in which the reflected rays meet, or tend to meet, and the distance between it and the centre of figure is the *principal focal distance*. In spherical mirrors, reflected rays do not absolutely meet at one point.

Focus of a Concave Mirror.—(1) Rays parallel to the prinpal axis, falling on a concave mirror, are reflected to meet in the principal focal point, which is at a distance from the mirror equal to half the radius of curvature. (2) If the rays emanate from the focal point, they will be reflected parallel to the principal axis, and will not form a focus. (3) Rays divergent from a point, will meet in a point outside the principal focus, between it and the centre of a curvature. (4) If the source of light be at the focus formed by the divergent rays, the reflected rays will now meet at what was originally (see 3) the source, and this point is called the *conjugate focus* because of the relation existing between the two. (5) The more the source of light approaches the mirror, the more does the focus approach the centre of curvature, because of the growing smallness of both angles formed. When the source is at the centre, the rays are perpendicular to the surface, are reflected in the same line and the two coincide. Conversely, the further off the source of light, the larger become the angles, and the more does the focus approach the principal focal point, until when infinity is reached, the rays become parallel, and meet in the principal focal point.

Real and Virtual Foci.—When the source of light is not nearer the mirror than the principal focus, the principal and conjugate foci are on the same side of the mirror as the source, and they are called *real foci*. If the source of light be nearer to the mirror than is the principal focus, the angle of incidence will be so large that the reflected rays become divergent from the axis, do not intersect, and hence form no conjugate focus. But, if they are conceived to be prolonged on the other side of the mirror, their prolongations will intersect in the same point on the axis, and the eye experiences the same impression as if the rays were directly emitted from that point which is called the *virtual focus*. This focus, then, is on the other side of the mirror.

Foci of convex mirrors are always virtual. (1) Parallel rays falling on a convex mirror, after reflection, take a divergent direction, but when continued *behind* the mirror meet in a point, the *principal virtual focus* of the mirror. This point is, approximately, the centre of the radius of curvature.

(2) Divergent rays falling on a convex mirror will, similarly, form a *conjugate virtual focus* between the principal focus and the mirror.

Formation of Images in Concave Mirrors.—(1) With divergent rays from an object beyond the centre of curvature, an image real, inverted and smaller than the object is formed between the centre of curvature and the principal focus. (2) If the object be at such a distance that the rays from it fall parallel on the mirror, the image will be at the principal focus. (3) As an object nears the centre of curvature, the image approaches it. If the object were at the centre, the two would coincide. (4) If the object be between the centre of curvature and the principal focus, an image real, inverted, and larger than the object will be formed far beyond the centre of curvature. (5) As the object approaches the principal focus, the image grows larger. (6) When it is at the principal focus, the rays are reflected parallel, and no image is formed, because there is no conjugate focus. (7) When the object is between the principal focus and the mirror, the rays after reflection diverge, and no real image is formed. But prolongation forms an image which is virtual, erect, and larger than the object. As the object approaches the principal focus, the larger becomes the image. As it nears the mirror, the smaller becomes the image.

Formation of Images in Convex Mirrors.—Whatever the position of an object in front of a convex mirror, the image is always virtual, erect, and smaller than the object.

CHAPTER XXV.

SINGLE REFRACTION OF LIGHT. PRISMS. LENSES.

Refraction is the deflection or bending produced when a ray of light passes obliquely from one medium into another. Rays perpendicular to the surface separating the two media, are not bent but continue in a straight line. A ray of light passing from a medium to one of greater density (as from air to water), is bent toward the normal or perpendicular. When it passes to one of less density, it is bent away from the normal (as from water to air).

Laws of Refraction.—(1) The incident and refracted rays are in the same plane. (2) The ratio of the sine of the angle of refraction to the sine of the angle of incidence is constant for the same two media, but varies with different media. This ratio is called the *refractive index.*

Total Reflection.—Sometimes, when a ray of light passes from a medium into one less dense, the angle of refraction is so great that the ray emerges parallel to the surface. This angle is a right angle and is called the *critical angle*, since for any greater one, the incident ray cannot emerge, but undergoes an internal reflection, called total reflection because the internal light is entirely reflected. There is no loss of light from absorption or transmission. The mirage is a phenomenon of refraction resulting from unequal density of the different layers of the air when they are expanded by contact with the heated soil.

Media with Parallel Faces.—When a ray of light passes through a transparent medium with parallel faces, it is refracted on entering, toward the normal, and on emerging, away from the normal; and when it leaves the medium, the emergent ray is parallel to the incident ray.

A prism, in optics, is any transparent medium bounded by two plane surfaces inclined to each other. The intersection of the two faces is the *edge;* and every section perpendicular to the edge is a *principal section.*

Path of Rays in a Prism.—When a ray of light strikes one of the inclined faces of a prism, it is refracted toward the normal; and when it reaches the second inclined face, it is again refracted, but now, away from the normal, and toward the base of the prism. Objects seen through a prism, therefore, appear deflected toward its summit. The angle formed by the direction of the incident ray with the direction of the emergent ray, expresses the amount of deviation caused by the prism, and is termed the *angle of deviation.* It depends, among other things, on the material of which the prism is formed, and expresses certain conditions, for there is a value in which the refracted ray would not emerge from the further face of the prism, but would be reflected from its internal surface towards the base. This is seen when a ray of light enters a prism whose principal section is an isosceles right-angled triangle. It makes with the hypothenuse an angle of such value as to cause reflection toward the base.

Lenses are transparent media with curved surfaces, which according to the direction of curvature, cause rays of light traversing them to either converge or diverge. The chief forms are double convex, plano-convex, concavo-convex, double concave, plano-concave, and convexo-concave. The first three, thicker at the centre than at the borders, are *converging*; the others, which are thinner at the centre, are *diverging.* Where a lens has two spherical surfaces, the centres for these surfaces are called the *centres of curvature*, and a straight line joining these is the *principal axis.* The *optical centre* is located on the axis, and any ray which passes through it emerges parallel to the incident ray. In doubly convex or concave lenses, the centre is in the lens; in plano-convex or plano-concave lenses, it is on the curved surface. Every straight line which passes through the optical centre without passing through the centres of curvature is a *secondary axis.*

Foci of Double Convex Lenses.—(1) Parallel rays of light falling on a convex lens are refracted twice toward the principal axis, and meet in a point on the principal axis (at the other side of the lens) called the *principal focus*. The distance between it and the lens is the *focal distance* of the lens. (2) If the source of light be at the focus, the rays will emerge from the lens parallel to each other. (3) If the source of light be outside the principal focus, but so near that the incident rays diverge, the latter will meet on the other side of the lens, at a point beyond the principal focus; and (4) if the source of light be at this point, the rays will come to a focus at the original situation of the light. These two points are *conjugate foci*. (5) As the light approaches the lens, the focus retreats, until when it is at the principal focus, the emergent rays become parallel to the axis, and there is no focus. The intensity of the light diminishes slowly, so that a lamp can illuminate great distances, when placed behind a convex lens. (6) The foci formed as above are all *real*. When the source of light is between the lens and the principal focus, the emergent rays diverge further, and no focus is formed. Prolongation backward will cause them to meet in a point on the principal axis, on the same side of the lens as the source of light. This is a *virtual focus*.

Foci of double concave lenses are always virtual. (1) Parallel rays are refracted divergent by double concave lenses, but prolongation backward causes them to meet at a point in the principal axis, called the *principal virtual focus*. (2) If the rays are divergent, a virtual focus is formed between the principal focus and the lens.

Formation of Images by Double Convex Lenses.—(1) An object placed at a greater distance from a lens than is the focal distance, has formed a real image, inverted and smaller than the object, situated near the principal focus but outside of it. (2) If a small object be placed near the principal focus, but a little outside of it, an image is formed real, inverted and much larger than the object, situated far beyond the focal distance. (3) When the object is between the lens and the principal focus, the emergent rays, instead of coming to a point, diverge. If prolonged backward, they will meet and there will be formed a virtual image, erect and larger than the object. Double convex lenses used thus as magnifying glasses, are called simple microscopes. The more convex the lens, and the nearer the object is to the principal focus, the greater is the magnifying power.

Formation of Images by Double Concave Lenses.—Like convex mirrors, double concave lenses form only virtual images (regardless of the distance of the object) which are erect and smaller than the object.

Spherical Aberration.—It has been assumed that all rays refracted by lenses meet in a point—the focus; but, as in the case of mirrors, this is not strictly true. Those rays passing through the circumference of the lens are refracted more, and, therefore, focussed sooner, than those passing through the more central parts of the lens. Images, therefore, placed in the exact focus, will be blurred at the circumference, and sharply defined at the centre. The defect is remedied by placing before lenses, diaphragms provided with apertures called *stops*, which admit the rays passing near the centre, but cut off those which pass near the edges. These give acute images, but lessen the illumination. The use of two lenses of double focal strength for one of short focus, will also destroy aberration, and will not lessen the illumination. Lenses corrected for spherical aberration are called *aplanatic*.

CHAPTER XXVI.

DISPERSION OF LIGHT. COLOR.

The Spectrum.—If sunlight directed through a narrow slit, pass through a prism, there will be formed a band composed of colors, as follows: Violet, indigo, blue, green, yellow, orange and red. This is called the *spectrum*. The colors are simple, i. e., they cannot be further decomposed. If, after producing the separation, which is called *dispersion*, a second prism is placed in the path of one of them, there results refraction, but the light remains unchanged. The colors are of unequal refrangibility, violet being most refracted, and red least.

Recomposition of White Light.—If the spectrum, as produced by a prism, be passed through a second prism identical with the first, but inverted, the latter will reunite the different colors; and it is seen that the emergent ray, which is parallel to the original one, is colorless.

Theory of the Spectrum.—Newton concluded from the facts above stated that white light was not homogeneous, but formed of seven lights each having its own degree of refraction, and these he called *simple* or *primitive* lights. The wave length of red light is longer than that of any of the other colors; and so, too, is its period. The wave length and the period decrease as the violet end of the spectrum is reached. Because of the difference in refrangibility, dispersion results as they pass through the prism. They are not separated by any sharp line, but gradually blend into each other.

Dark Lines of the Solar Spectrum.—When sunlight is used for the production of the spectrum, there are seen a great number of dark lines throughout its whole length, but at unequal intervals. They are called Fraunhofer's lines, and are indicated by letters: A, a, B, C, D, E, b, F, G, H. A, B, and C are in the red; D, in the yellow; E, in the green; F, in the blue; G, in the indigo; and H, in the violet ray. These lines are fixed, and are due to the absorption of certain rays in passing through the atmosphere surrounding the sun.

Spectrum Analysis.—If sodium be rendered incandescent and an arrangement be made for obtaining the solar spectrum near it, it will be found that two very bright yellow lines will appear corresponding in position to the dark lines, D. Each substance, when vaporized, gives definite lines which are formed by no other substance,—but a very small quantity sufficing—and thus there is afforded a powerful means of analysis.

The *spectroscope* is an apparatus employed for the purpose of spectrum analysis. It consists of three telescopes all giving on a prism, through one of which the observer sees the spectrum. The second telescope has at its outer end a lens which converges the light of the substance burned to the principal focus of a second lens placed at the inner end of the telescope. The pencil thus formed is composed of parallel rays, which enter the prism, are decomposed, and fall on a lens at the inner end of the first telescope. By means of this, a magnified and inverted image is formed in the tube, but by the lens in the outer end of the first telescope, the observer sees a virtual image of the spectrum magnified about eight times. The opening through which the light enters the second tube, is a narrow slit, which can be made larger or smaller by a screw. For purposes of comparison, a small rectangular prism is placed over the upper part of the slit, and rays from a flame falling on it, are reflected up the tube without mixing with the rays passing from the first flame. The third telescope has at its outer end, a scale for measuring the relative distances of the lines of the spectrum. It is placed in the principal focus of a lens in the inner end of the tube, and when the scale is lighted by a flame at the outer end, the rays emitted leave the tube in parallel pencils, some of which are reflected by one of the faces of the prism to the observer's eye.

The *use of the spectroscope in physiology* has been chiefly devoted to the observation of the *absorption bands* of the various constituents of the blood. If a thin layer of undiluted blood be placed before the slit, only the red end of the spectrum will be seen. As the blood is diluted more and more, the various colors appear until the whole spectrum comes forward. Between D and E, however, are observed two dark bands, the one to the violet side of D being more intense, while that to the red side of E is the broader of the two. These are the *absorption bands of O-hemoglobin.* When hemoglobin has been deprived of its oxygen, the two bands are replaced by a broader one, situated also between D and E, but nearer to the red end. More of the blue end of the solar spectrum is observed—hence the color of venous blood. This is the *absorption* band of reduced hemoglobin. The *bands of CO-hemoglobin* are similar to those of O-hemoglobin, but are slightly displaced toward the violet end of the spectrum. *Acid hematin*, produced by the action of an acid on blood, gives one band in the red near C; while *alkali hematin*, produced by the action of an alkali, gives one dark band to the red side of the D line. The importance of these in medico-legal investigations can be readily seen.

Properties of the Spectrum.—These are not confined to any particular portion of the spectrum; but one is more definite in one part, and another in another part.

The *luminous properties* are most intense in the yellow part of the spectrum, and least in the violet.

The *heating effects* of the visible spectrum are most pronounced in the red end; but beyond these, are rays invisible to the eye, which possess even greater heating properties. They are called the *ultra-red rays*, and have been detected as far beyond the extreme red as the whole length of the visible spectrum. Substances which are opaque, as it were, to heat rays, i. e., absorb them and become heated, are called *athermanous* bodies. Those which transmit, i. e., are transparent to, heat rays, are *diathermanous*, e. g., rock-salt, iodine, etc.

The *chemical properties* of the spectrum reside chiefly in the violet end, but beyond this, there exist *ultra-violet rays* which exhibit more powerful chemical effects than the visible violet. These are called actinic rays. Chloride of silver blackens under the influence of light, but this takes place more energetically when the chemical is placed in the violet rays.

Fluorescence, which was first discovered in fluorspar, is due to a change of refrangibility in rays of light. It is seen when a solution of sulphate of quinine, contained in a flask with parallel sides, is placed in different positions in the solar spectrum. No change is observed in the red and yellow, but from about the indigo to some distance beyond the extreme range of the violet, rays of a beautiful sky-blue color are seen to proceed. In other words, the length of the visible spectrum is increased and the solution becomes self-luminous.

The change arises from a diminution in the refrangibility of those rays outside of the violet, which are ordinarily too refrangible to affect the eye. A solution of *esculine* (extracted from the horse-chestnut), an alcoholic solution of stramonium, or a plate of canary glass also renders visible the ultra-violet rays. These substances do not exhibit this property in the other colors of the spectrum, although they do so in white light; an alcoholic solution of chlorophyll, however, gives red light throughout nearly the whole range of the spectrum. The explanation of this phenomenon is that the molecules of a fluorescent body will absorb vibrations of its own period, and being thrown into activity, will itself produce the vibrations. Light of the same color as the body itself emits, it will absorb and emit, but light of a less refrangibility, of a slower speed, it will permit to pass unaffected. It will also be thrown into vibration by vibrations of a higher speed than its own, but when thus excited, its molecules will vibrate with their own rapidity. The solution of sulphate of quinine is visible only in the ultra-violet, while that of chlorophyll may be seen almost throughout the whole spectrum.

Phosphorescence is the property possessed by certain bodies of becoming luminous in the dark without any considerable rise of temperature, due to a slow oxidation. It may also be produced by a rise of temperature, by mechanical effects and by electricity. One of the most important causes is insolation or exposure to direct sunlight. The sulphides of calcium and strontium are the best phosphorescents, but the property is exhibited by other substances. The different rays of the spectrum do not in equal degree communicate it. The greatest effect is produced by the ultra-violet rays, but the light emitted by the bodies is usually of less refrangibility, thus showing its relation to fluorescence. Both of them can be produced when the substance to be examined is subjected to electricity by means of a Crookes' tube.

The **Roentgen** or **X-ray**, discovered in 1896, is a form of energy radiated from highly exhausted Crookes' tubes, actuated by induction coils or electrostatic machines. Roentgen, the discoverer, for whom the rays have been named, called them X-rays, the term X being used in algebra for the unknown quantity. The rays resemble ordinary light in being propagated in straight lines, in being capable (although in but a slight degree) of reflection, in causing phosphorescence, and in affecting a sensitized plate. They differ from ordinary light in being invisible, in not being capable of refraction or polarization, and in being able to traverse many substances opaque to ordinary light.

The *Crookes' tube* (focus tube), as ordinarily used, consists of a highly exhausted glass bulb whose cathode is concave, and whose anode is plane and made of platinum. The anode is inclined at such an angle that the X-rays generated on its surface by impact of the negative rays, are thrown out through the side walls of the tube.

Nature.—There are two theories regarding the nature of the X-rays, viz., (1) that which regards them as an undulatory phenomenon of ether; (2) that which looks on them as streams of particles or fluid. Those who accept the first theory, and they are the majority, are divided into two classes: (a) Those supposing the rays to be simply ultra-violet light of wave length far shorter than any that has been hitherto observed, and (b) those supposing the rays to differ from ordinary light in the direction of the vibration which instead of being transverse to each ray, is longitudinal, as in the case of sound waves. The ultra-violet theory is the one generally accepted.

Methods of Observation.—The object to be examined is placed between the Crookes' tube and the holder containing the sensitized plate. A long exposure is necessary to obtain a picture of the object. To obviate this, Edison invented the *fluoroscope*, consisting of a box, narrow at one end for the eyes of the observer, and broader at the opposite end, which is covered with a substance treated with calcic tungstate, a fluorescent. Any fluorescent may be used. The fluoroscope takes the place of the sensitized plate, and the observer obtains a direct view of the body under examination. The pictures as obtained, have received various names: Shadowgraphs, radiographs, skiagraphs, etc.

Uses.—The X-ray has come into extensive cmployment in surgery for the location of bullets, of fractures and their nature, of foreign bodies in the alimentary canal, etc.

Color.—The frequency of vibration of rays determines color. The natural color of a body depends upon the fact that one portion of the colored rays making up white light is either reflected or transmitted by that body, the other portions being absorbed. Those reflecting or transmitting all the colors as they exist in the spectrum are white; those which do neither are black.

Mixed colors give a single impression on the retina, resulting from the simultaneous action of two or more colors. Helmholtz investigated these by making two very narrow slits, at right angles to each other, in the shutter of a dark room. At a distance, he placed a powerful dispersing prism. Viewed with a telescope, it is seen that the slits give oblique spectra, two homogeneous spectral colors, as they are called, overlapping. The following table gives Helmholtz's results:

	Violet	Indigo	Bluc	Green Blue	Green	Yellow Green	Yellow
Red.......	Purple	Deep Rose	Light Rose	White	Light Yellow	Golden Yellow	Or'nge
Orange..	Dcep Rose	Light Rose	White	Light Yellow	Yellow		
Yellow ..	Light Rose	White	Light Green	Light Green	Green Yellow		
Yellow Green....	White	Light Green	Light Green	Green			
Green....	Light Blue	Blue	Green Blue				
Green Blue......	Blue	Blue					
Blue......	Indigo						

The mixture of colors can also be investigated with Maxwell's color discs, which are discs of card-board painted with the colors of the spectrum, and made to rotate on a turning table.

Fundamental and Complementary Colors.—Referring to the table, it is seen that red and green-blue produce white light, as do, also, violet and yellow-green. Because of the fact that these colors, mixed, give white light, they are said to be *complementary* to each other. Green-blue and yellow-green together produce green, so that a mixture of this with red and violet will produce white; and by using varying proportions, as shown by the rotating disc, all possible colors may be constructed. Because of this, red, green and violet are called *fundamental* or *primary colors.*

Spectral and Pigment Colors.—In a mixture of two or more differently colored pigments, the resulting color is not due to the addition, but rather to those rays which have escaped absorption. Although a mixture of spectral blue and yellow produces white light, a mixture of pigments of the same colors results in green; for the blue absorbs almost entirely the yellow and red light, and the yellow absorbs the blue and violet light, leaving green as the determining color.

Properties of Color.—(1) The *tint*, or *tone*, or color proper, is due to the predominating color in the mixture. (2) *Saturation* depends on the amount of mixture of white light with the colors. Those of the spectrum are fully saturated—i. e., free from white light; but the production of tints by the three fundamental colors never possess the saturation of the spectral colors. (3) *Intensity* depends on the amplitude or extent of vibration.

Homogeneous or monochromatic light is that which is absolutely pure. The light given out by luminous bodies is seldom quite homogeneous.

Perception of Color.—Color is a subjective sensation; i. e., it proceeds from within.

The Young-Helmholtz theory assumes that three different kinds of nerve elements, corresponding to the three primary colors, are present in the retina, stimulation of which produces the sensations of red, green and violet light, respectively. In the scheme shown, the line 1 represents the rays producing the sensation of red; 2, those producing the sensation of green; and 3, those producing the sensation of violet. Pure red light strongly excites the elements sensitive to red, and feebly, those sensitive to green and violet. Pure blue excites moderately the elements sensitive to violet and green; and feebly, those sensitive to red.

Chromatic Aberration.—As a lens may be said to be a combination of prisms, with the angles rounded off in the case of a convex lens, it follows that it would not only refract light, but also disperse it. Objects viewed through a lens at a certain distance from the eye, have colored edges. This is called *chromatic aberration.* Violet rays being refracted most, come to a focus nearer the lens than do the other colors, red rays being focussed last. The more convex the lens, the greater is chromatic aberration.

Achromatism.—By combining prisms of different refracting angles, and formed of materials of unequal dispersive powers, white light may be refracted without being dispersed. This is true also of lenses, the curvatures of which are suitably combined. The refraction is not overcome in equal degree with the dispersion, and therefore, the emergent ray is not exactly parallel with the incident ray. By combining a convexo-concave lens of flint glass with a double convex lens of crown glass, a condition is brought about whereby objects, when seen through such a combination, do not appear colored. Such a lens is called *achromatic.* To obtain perfect achromatism, several such systems would be required. In optics, therefore, it is sought to combine the most luminous rays, viz., orange and blue. Simultaneously, it is sought to avoid spherical aberration.

CHAPTER XXVII.

OPTICAL INSTRUMENTS.

The **simple microscope**, or magnifying glass, is a convex lens of short focal length, through which objects placed between it and its principal focus are viewed, and are seen to be virtual, erect and magnified. Both chromatic and spherical aberration increase with increased magnification. The former can be corrected with achromatic lenses, and the latter by stops or the use of two plano-convex lenses instead of one double convex lens. The plane face of each lens is turned toward the object. The combination is known as Wollaston's doublet. The nearer the object is to the principal focus while within it, the greater is the magnification.

The **compound microscope,** in its simplest form, consists of two condensing lenses—the *objective*, of short focus and turned towards the object; and the *eye-piece*, less condensing and close to the observer's eye.

The figure shows the path of the rays and the formation of the image in this form of a microscope. The object is placed just a little beyond the principal focus of the objective which forms a real, magnified, inverted image on its other side. The position of the eye-piece is so regulated that the image falls within its principal focus, and it produces a virtual, erect and highly magnified image, rays from which proceed to the eye to be directed outward toward the object. What is really seen is the image of an image.

Corrections of Aberrations.—As with simple microscopes, the greater the magnifying power of the lenses, the greater are the aberrations. Huyghen's eye-piece, originally applied to the telescope, was adapted by Campani to the microscope. It consists of two lenses—the *eye-lens*, to which the eye is applied, and the *field-lens*, which is turned to the object, the distance between the two being equal to half the sum of their focal length. Such an eye-piece is achromatic; for the field-lens disperses the rays from the object, and these rays are converged and rendered parallel by passing through the eye-lens. By drawing the rays toward the axis, the eye-piece is at the same time, made aplanatic; and spherical aberration is also corrected by a stop placed between the two lenses. Such an eye-piece has another advantage, in that it enlarges the field of view.

To correct aberrations in the objective, it is made of three pairs of lenses, each pair of which is formed of a double convex lens of crown glass cemented to a plano-concave lens of flint glass. By this means, it is sought to combine all the spectral colors, and thus render the objective completely achromatic. One lens corrects the faults of the other. Such highly corrected lenses also increase the angular aperture, thus providing better illumination.

Immersion lenses used for great magnification, dip into liquids placed on the cover glass of the slide. The difference between the refractive indices of liquids and glass is not as great as between those of air and glass, so that there is not as much refraction, and consequently more illumination, when the medium separating the cover glass from the objective is a liquid. Cedarwood oil is generally used with immersion lenses, because its refractive and dispersive powers are nearly equal to those of glass.

The **camera lucida** is an instrument depending on internal reflection, and serves for making a drawing of a magnified image. *Chevalier's* camera lucida is fixed to the microscope after removal of the eye-piece of the latter. Rays of light proceeding up the tube of the microscope, strike the internal surface of the inclined face of a rectangular prism and are reflected at right angles into the camera tube, at the end of which is a second prism which reflects the rays into the observer's eye above. At the same time, rays proceed from a sheet of paper and the point of a pencil placed ten inches below (the distance of distinct vision). The eye always referring directly outward rays coming to it, sees the image on the paper, and a drawing can be made.

The *neutral tint reflector* consists of a circle of tinted glass set in a ring at an angle of 45°, the ring being fitted on the eye-piece of the microscope which is placed horizontal. Rays passing up the tube of the microscope strike the glass which reflects them to the observer's eye. Rays from a piece of paper below, also pass up to the eye, and as in the case of Chevalier's instrument, a drawing of the object can then be made.

The **laryngoscope** has for its object the illumination of the fauces, pharynx and larynx. It consists of a small mirror fixed to a long handle, at an angle of 125° to 130°. The mouth is opened, the tongue drawn forward, and the mirror is introduced. A reversed picture of the part of the larynx examined is formed in the small mirror, the rays of light passing through the mouth into the eye of the observer, who must place himself in the direction of the reflected rays. The illumination of the larynx is accomplished in several ways. The usual method is a lamp which is placed to one side and slightly behind the patient. The observer, who is seated directly in front of the patient, has strapped to his forehead a concave mirror pierced at its centre by a small hole through which he looks. Rays of light strike the concave mirror, and are reflected through the mouth of the patient upon the small mirror held in the back part of the throat. The beam of light is reflected at the same angle toward the larynx by the throat mirror so that the larynx is brightly illuminated, and its picture is seen by looking at the throat mirror through the opening in the head mirror.

The **ophthalmoscope** is an instrument, invented by Helmholtz, designed for the examination of the eye. It consists of a concave reflector of glass or metal, in the middle of which is a small hole; and of a converging lens which is held in front of the eye of the patient. A lamp being placed to one side and a little behind the patient, the observer, holding in one hand the reflector, employs it to concentrate the light, and with his other hand holds the achromatic lens in front of the eye. By this arrangement, the back of the eye is lighted up, and its structure can be clearly seen and studied. The figure shows how the image of the back of the eye is produced. Let ab be the part of the retina illuminated. Pencils of rays proceeding from it, would form its inverted and aerial image at a′b′. But these pencils, when they leave the eye, pass through the converging lens O, and thus the image a″b″ is formed, inverted (and magnified about four times), but distinct, and in a position fit for vision. This method is called indirect ophthalmoscopy, and it gives a more general view of the fundus of the eye than the direct method which dispenses with the converging lens.

Ophthalmoscopes as now used, are provided with two metal discs carrying a complete series of convex and concave lenses which can be rotated behind the aperture of the mirror. The mirror can be inclined at an angle, so that light can be reflected into the patient's eye even when the ophthalmoscope is almost touching it. In this form, the converging lens is dispensed with, the lenses behind the mirror being rotated to cover the aperture and correct anomalies, either in the observer's or the observed eye, or both. The image formed is erect and magnified about twenty times.

A recent invention, for the purpose of illumination of the throat, eye, or other accessible body cavities, consists of a metallic case (which is fastened by a strap to the head) bearing in front a strong converging lens. Behind the lens is a small incandescent, electric lamp. The whole apparatus can be turned in any angle.

The **camera obscura** is a dark box, four sides of which are formed of a bellows. In front, is a brass tube containing an achromatic condensing lens. At the opposite end, is a ground glass which can be displaced by a holder containing the sensitive plate. The camera being in position before the object, the bellows is lengthened or shortened by a rackwork and pinion until the image on the ground glass is very sharp. This is so when the glass is in the exact focus of the lens. Spherical aberration is corrected by means of stops.

CHAPTER XXVIII.

THE EYE AS AN OPTICAL INSTRUMENT.

Structure of the Human Eye.—The general shape is that of a sphere, pierced near its centre by the optic nerve. The white of the eye, which forms nearly the whole wall of the organ, is the *sclerotic coat*. It is lined by the *choroid coat*, a black substance, which converts it into a dark chamber.

The *cornea* is a transparent substance, circular in form, and completing the anterior segment of the eye. The *iris* is an annular, opaque diaphragm, pierced at its centre by a hole called the *pupil*. It contains two sets of fibres, one dilating the pupil, called the *dilator pupillæ;* the other contracting it and called the *sphincter pupillæ*. Its posterior surface is black. Between the iris and the cornea is the *anterior chamber*, containing a transparent liquid called the *aqueous humor*. Immediately behind the iris is the *crystalline lens*, double convex in shape, and made up of a number of concentric layers like the coats of an onion. The lens is enclosed in a membrane called its *capsule*, attached to the anterior surface of which is another membrane called the *suspensory ligament*. The *ciliary processes* are a number of folds formed by the anterior termination of the choroid, which dip between the iris and capsule, and give attachment to the *ciliary muscle*. Behind the lens is the *posterior chamber*, which contains a jelly-like substance called the *vitreous humor*. It is enclosed by the *hyaloid membrane*, which lines the posterior face of the crystalline capsule, and the inner face of another membrane called the *retina*. The retina is simply the expansion of the optic nerve after it has pierced the eyeball, and it partly lines the inner surface of the choroid. It is formed of several layers, the most important of which is that of the *rods and cones*. Where the nerve enters the ball, is the *blind spot*, and there are no rods and cones at that place. In the axis of vision, a little to the outer side of the optic entrance, is a point named from its color *macula lutea* or *yellow spot;* and in the centre of it is a depression called the *fovea centralis*. Here vision is most distinct, for it is composed entirely of rods and cones.

Path of Rays in the Eye.—The eye may be likened to a camera obscura, having the crystalline for a condensing lens, the retina for the screen upon which the image is formed, and the iris for a diaphragm whose aperture can be made larger or smaller by the action of the pupillary muscles. The effect, then, is the same as when the image of an object placed in front of a double convex lens, is formed at its conjugate focus. Suppose rays proceeding from an object placed before the eye. Only those directed toward the pupil pass into the eye and tend to produce vision. Passing into the aqueous humor, they are refracted to near the secondary axis, which is drawn through the optic centre of the crystalline; they then traverse the lens which refracts them a second time, and, having undergone a third refraction by the vitreous humor, they meet in points on the retina and form an image which is very small, real and inverted.

Inversion of Images.—That the images formed on the retina are inverted can be proved by removing the eye of an animal in a dark room, opening it, and "fixing" the retina with alum.

The *principal optic axis* of the eye is the axis of its figure. It is a straight line passing through the centre of the pupil and of the crystalline. The eye sees objects most distinctly in its direction, for rays of light following it fall upon the yellow spot where vision is most acute. The *optic angle* is the angle formed between the principal optic axes of the two eyes when they are directed toward the same point. Its size is inverse to the distance of the object. The *visual angle* is the angle under which objects are seen. It is formed by the secondary axes drawn from the optic centre of the crystalline to the opposite extremities of the object. For the same distance, it increases with the magnitude of the object; and for the same object, it decreases as the distance decreases. Therefore, the further off the objects are, the smaller do they appear. Several objects of varying size and distance, when seen under the same angle, appear to be of the same size.

Sharpness of vision depends upon the power possessed by the eye of distinguishing two points as separate. The smallest object that can be seen at the distance of a foot, is 1-250 of an inch, which subtends an angle of about one minute. The retinal image, corresponding to a visual angle of one minute, has been calculated to be about .004 mm., or 1-6000 of an inch, which is the diameter of a cone. Two points seen under an angle of one minute, would appear as one. In ophthalmoscopy, sharpness of vision is tested by types of various sizes, arranged to be read under an angle of five minutes. If D is the distance at which the types ought to be read, and d, the distance under which they are read, then sharpness of vision is determined by the formula

$$V = \frac{D}{d}.$$

When d=D, vision is normal.

Accommodation is focussing the eye for near vision. Parallel rays falling on the *emmetropic*, or normal, eye, are focussed on the retina. These rays proceed from infinity; but divergent rays—i. e., those coming from a finite distance—are not focussed in the normal eye except by an effort. This effort results in a contraction of the ciliary muscle, which causes relaxation of the lens capsule; and this, in turn, permits bulging forward of the anterior portion of the crystalline lens. The consequence is, that the lens becomes more convex, its refractive power is increased, and divergent rays, which would be focussed behind the retina and form blurred images, are now brought to points on the retina and form sharp images. Accompanying accommodation are contraction of the pupil and convergence of the eyeballs.

Purkinje's images demonstrate the truth of what has been said. If a candle be held on one side of the eye of a person looking at a distant object, there will be seen three distinct images of the flame: The first is virtual and erect, reflected from the anterior surface of the cornea; the second, erect and less bright, reflected from the anterior surface of the lens; and the third, inverted and brilliant, reflected from the posterior surface of the lens. If, now, a near object is looked at, no change is observed in the first and third images; but the second image becomes smaller and approaches the first.

The Range of Accommodation.—Rays of light falling on a normal eye from a distance not less than sixty-five metres, do not require accommodation. This, then, is the *far point* or *punctum remotum* of distinct vision. There is a point near the eye, inside of which rays cannot be focussed on the retina, because the convexity of the lens required cannot be attained. This is the *near point* or *punctum proximum.* Between these two is the range of accommodation. The *distance of distinct vision* is the distance at which objects must be placed to be seen with the greatest clearness. Normally, it varies from ten to twelve inches for small objects, such as print.

Spherical aberration does not exist in the eye because of the iris.

Presbyopia is the condition of farsightedness existing in the aged, and is due to diminished elasticity of the lens. The far point becomes further and further removed because of loss of the power of accommodation. It is corrected by the use of convex lenses.

Anomalies of Refraction.—(1) *Myopia*, or shortsight. In this, both the near and far points are closer to the eye than in the normal condition. The myopic eye is longer than usual, and the rays of light coming to it are focussed before they reach the retina. Therefore, the affected person must have the object within the normal near point for distinct vision. The condition is corrected by the use of concave lenses. (2) *Hypermetropia*, or farsight. Here, the eye is usually smaller than the normal eye. Rays of light, therefore, are not focussed on, but behind the retina, and a blurred image results. The affected person holds the object, such as a book, beyond the near point, so that the luminous rays proceeding from it may be focussed on the retina. The condition is corrected by the use of convex lenses. (3) *Astigmia*, or astigmatism. Should one of the surfaces of the media of the eye have a curve of shorter radius in one of its meridians, all the rays from a luminous point cannot be focussed in the same plane, but will possess two linear foci—one anterior, corresponding to the curvature of shorter radius; and the other behind, corresponding to the curve of greater radius. The cornea is the medium usually affected, but sometimes the lens is also affected. The condition is corrected by the use of cylindrical lenses. It is usually sought to add to the curvature of the meridian with less curvature. If the vertical meridian is the one affected, a horizontal cylinder is employed; and if it is the horizontal meridian, a vertical cylinder is employed.

Achromatopsy, or *color blindness*, is a defect of vision in which there is inability to distinguish between certain colors. Red blindness is the most common form of this defect.

CHAPTER XXIX.

DOUBLE REFRACTION. INTERFERENCE. POLARIZATION.

Double refraction is the property possessed by a large number of crystals, whereby a single incident ray, in passing through any one of them, splits in two; and, therefore, an object when seen through one of these crystals, appears double. Iceland spar (crystallized calcium carbonate) possesses this property in a remarkable degree. Crystals belonging to the cubical system, and substances which, like glass, do not crystallize, have no double refraction. They can, however, acquire it when unequally compressed, or when they are cooled quickly after being heated, in which state glass is said to be *unannealed.* The two images formed by a crystal of Iceland spar (which is rhombohedral in shape) are of equal brilliancy. Double refraction has been explained by the assumption that the ether in these bodies is not equally refractive in all directions, and, therefore, the vibrations are transmitted with unequal velocities. *Ordinary* and *extraordinary* are the names applied to the rays arising from an incident ray when it enters the doubly refractive crystal. If the crystal of Iceland spar be held over a black dot and rotated, it will be seen that one of the images remains stationary while the other revolves about it. The first image is produced by the ordinary ray which passes through the crystal as it would through any simple refracting substance. The second image is produced by the extraordinary ray which is not retarded so much as, and has a greater velocity than, the ordinary ray. The ordinary laws of refraction do not apply to this ray.

Uniaxial Crystals.—In all double refractive crystals, there is one direction in which a ray of light will be transmitted without double refraction. This is the direction of the optic axis. Crystals with one optic axis are called uniaxial, and those used most frequently are Iceland spar, quartz, and tourmaline. Iceland spar has six surfaces, three of which meet at one angle to form an obtuse angle; and at the lower opposite angle three surfaces also meet, to form a second obtuse angle. The other angles are acute. A diagonal line joining the obtuse angles is the *optic axis of the crystal.* The plane of the axis is called a *principal plane*, and any plane parallel to this, is also called a principal plane. If the obtuse angles be cut off by a plane at right angles to the axis, the surface thus made will also be at right angles to it. Any ray falling perpendicularly on this surface, is parallel to the axis and will pass through the crystal without being doubly refracted. Therefore, in every section perpendicular to the optic axis, the extraordinary ray follows the law of single refraction.

A **Nicol's prism** is made from a crystal of Iceland spar which is cut in two through its obtuse angles. The halves are then joined in the same order, with Canada balsam whose index of refraction is less than the ordinary index of Iceland spar, but greater than its extraordinary index.

Polarization of Light by Double Refraction.—When a ray of light falls on a Nicol's prism, it undergoes double refraction, the extraordinary ray passing through the junction and emerging in a direction parallel to the entering ray; while the ordinary ray is totally reflected by the balsam, and takes a direction by which it is refracted out of the crystal; so that the extraordinary ray emerges alone. It was said that a spot looked at through a crystal of Iceland spar appears double, both images being of equal intensity. Looking at these through a second crystal, each is generally doubled, but the four images are of unequal brightness. By turning either of the crystals, it is found that there are positions at right angles to each other, in which only two images are visible. Turning further, the lost images appear—faint at first, but gradually becoming brighter while the others become fainter in proportion, till, when a quarter of a revolution has been completed, the new images alone remain, the others having disappeared. Using two Nicol's prisms instead, it is found that when their principal planes are parallel a circle of light is seen, and at its greatest intensity. Rotating one of the prisms, the light gradually fades until, when a right angle has been passed through, it disappears. Continuing the rotation, the light gradually reappears until a second right angle has been passed through, when again it is at its brightest. From this, it follows that each of the rays into which a single beam of light is decomposed by double refraction possesses sides, or is *plane polarized*, and to such an extent as to be incapable of being again doubly refracted in certain positions of the second crystal. *Explanation.*—Ordinary light is the same all round. Its particles of ether move in a direction transverse to that of propagation. The vibrations occur in all planes across the direction of the wave, and the particles, in vibrating, may describe circles, lines, etc. But when light is polarized, the particles vibrate in straight lines and in one plane only. An ordinary ray of light may be said to be decomposed into two rays polarized in planes at right angles to each other, and moving with different velocities. A single Nicol's prism does not reveal this condition to the eye, but, when aided by a second prism, it is made apparent. The first prism is called the *polarizer*, and the second the *analyzer*.

Polarization by Reflection.—A ray of light falling on a polished, but unsilvered glass surface, inclined at a certain angle, has its reflection polarized. This can be demonstrated by allowing the reflected ray to fall on a crystal of Iceland spar and manipulating the latter in the manner described, when the phenomena of light and darkness will be seen. It can also be exhibited by permitting the reflected ray to fall on a second surface of unsilvered glass inclined at the same angle. If the second surface be turned out of this position, the intensity of the light diminishes, and finally disappears when it is at right angles to the first surface. Continued rotation results in gradual restoration of the light, until, when the two are parallel, the maximum is again reached.

The *angle of polarization* is the angle which the incident ray must make with the perpendicular of the reflecting surface in order that there be total polarization. The *plane of polarization* is the plane of reflection in which the light becomes polarized. As it coincides with the incident plane, it contains the polarizing angle.

Detection of doubly refractive substances may be accomplished by interposing the suspected substance between two Nicol's prisms in a position in which its principal plane does not coincide with that of either of the two prisms. If the two prisms be at right angles to each other, in which case there is darkness, interposition of the suspected substance will cause light to appear. *Explanation.*—When the two prisms are at right angles, there is darkness because of the extinction of the extraordinary ray. When the plate is introduced at an angle of 45°, light appears. The extraordinary ray of the first Nicol may be split into two rays (at right angles to each other), extraordinary and ordinary, the former of which vibrates in the plane of the interposed plate. These two rays meet the second prism, which, however, can only transmit vibrations in its own plane, and this is at right angles to the first prism. The vibrations in the plane of the plate can be decomposed into a vibration in the plane of the first Nicol, which is extinguished, and one in the plane of the second Nicol. The other subray of the first Nicol can be decomposed into two vibrations at right angles, one vibrating in the plane of the first Nicol, which is again extinguished, and the other in the plane of the second Nicol.

Interference.—Using a very thin plate of selenite, or mica, instead of the thick crystal of Iceland spar, it is seen that the light is no longer white, but of a uniform tint, the color of which depends upon its thickness. Having the plate so fixed that the light is at its brightest and the color red, turn the analyzer. The color becomes fainter, and when it has been turned through 45°, disappears. Continuing to turn, the complementary color, green, appears, increases in intensity until the analyzer has gone through 90°, after which the intensity diminishes until an angle of 135° is reached, when light again disappears, to be replaced by red on turning further. The *explanation* of this phenomenon is the same as that for depolarization which was described previously. The subrays, although vibrating in the same plane, travel with different velocities, double refractive substances, as has been said, being not equally elastic in all directions. The ordinary and extraordinary subrays, then, not coinciding with each other, interfere, and there results, as a consequence, extinction of certain portions of the white light, that color which survives determining the tint which is seen with the aid of the analyzer.

When the incident rays traverse the plate under different obliquities, instead of perpendicularly to its faces, as described above, colored rings are formed similar to Newton's rings. The latter are seen in soap bubbles; in steel, covered with a thin layer of oxide; in a drop of oil spread rapidly over a large surface of water, etc. Newton's rings are explained on the theory of interference. A ray of light falling on a thin, transparent body, will be partially reflected and partially refracted. The refracted ray will undergo another reflection at the opposite surface, the direction being the same as that of the first reflected ray. The two reflected rays will destroy or increase each other's effect according as they are in the same or different phases.

Circular Polarization.—If a plate of quartz (rock crystal) be placed between the polarizer and analyzer, there will be no extinction of light, whatever the position may be. The spectral colors, beginning with red and ending with violet, pass in review as rotation is continued. As has been seen, the principal planes of two Nicol's prisms must be at right angles to each other in order that light be extinguished. But when the piece of quartz is interposed and red light appears, the analyzer must be turned through 60° to meet at right angles the polarized ray and overcome it. The plane of polarization has been rotated by the quartz. For each color, the degree of rotation is different, so that it appears at certain intervals. *Explanation.*—A ray of light passing along the axis of the crystal, is divided into two rays of circularly polarized light of equal intensity but different velocity. One passes to the right, the other to the left. On emerging from the crystal, they form a plane polarized ray; but as they move through it with unequal velocities, one of the rays will have emerged before the other, and vibrates in a certain direction when it receives an impulse from the second ray which vibrates in the opposite direction. The result is a plane polarized ray rotated to the right or the left according as the right-handed or left-handed ray moves with the greater velocity. There are two kinds of quartz, one *dextrorotatory* (rotating the plane to the right), the other, *lævo-rotatory* (rotating the plane to the left). The amount of rotation depends upon the thickness of the plate. Among substances rotating the plane of rotation to the right, are cane-sugar, dextrose, essence of lemon, lavender, etc. Lævo-rotatory substances are levulose, albumen, gelatine, etc.

The **saccharimeter** is an instrument devised for the detection of sugar in solution, and the determination of its strength. Simply, it consists of a polarizer and an analyzer (two Nicol's prisms) between which is placed a tube filled with a solution of sugar. Before the tube is inserted, the Nicols are turned at right angles to each other so that the field is dark. When the tube containing the solution is interposed, illumination ensues. By means of a screw, the analyzer is turned till darkness again supervenes, and the amount of rotation, which gives the rotatory power of the solution, is read off on a scale. The amount of rotation is governed by the amount of sugar in the solution and the length of the column of liquid. For every gramme of sugar in 100 cc., the rotation is 1.333° in a tube 20 cm. long.

In Soleil's saccharimeter, interposed between the polarizer and the tube, is a plate of dextro-rotatory quartz cemented to one that is lævo-rotatory, each being cut perpendicularly to the axis and of the same thickness. When the prisms are parallel, they give a rose-violet tint called the *transition tint.* Turning the plane of polarization causes one-half the field to change to red, and the other half to violet. Instead of rotating the analyzer to restore the original tint, in Soleil's apparatus what is called a *compensator* is used. It destroys the rotation of the column of liquid, and consists of two quartz plates with the same rotation either to the right or left, but opposite to that of a single plate of quartz which is placed between it and the tube. The plates are wedge-shaped and are made to slide over or away from each other by means of a screw. The effect is to increase or decrease the thickness of the quartz plate which they compose. If the solution has rotated the plane of polarization to the right, the screw is turned until a sufficient thickness of the quartz plate rotating to the left is interposed to compensate for the rotation produced by the sugar.

In *medicine* this instrument is used for determining the amount of sugar in diabetic urine. To estimate it, the urine is heated with acetate of lead and filtered. The tube is filled with the clear liquid thus obtained, and the screw turned until by means of the compensator, the same tint is obtained as previous to the interposition of the urine. Each division of the scale represents 2.256 grains of sugar. The number indicated at the time the original tint appears must be multiplied by 2.256 to obtain the quantity of sugar in the given amount of urine.

ACOUSTICS.

CHAPTER XXX.

NATURE, REFLECTION AND REFRACTION OF SOUND.

Nature of Sound.—Sound, like light, is considered a mode of motion due to undulations or oscillations which comprise movements to *and* fro. Like those of light, the vibrations may be reflected and refracted; but, unlike them, they are regarded as longitudinal to the direction of propagation, and they are not propagated in a vacuum.

A *complete vibration*, or sound wave, comprises the oscillation both backwards and forwards, the movement forwards being a *condensation*, and that backwards a *rarefaction* or *expansion*. The distance between the position of rest and either extreme is the *amplitude* of a vibration. Particles are said to be in the *same phase* when they occupy the same relative position, and move with equal velocities in the same direction. They are said to be in *opposite phases* when they move with the same velocity in opposite directions.

The **intensity** of sound is (1) inversely proportional to the square of the distance of the sounding body from the ear. (2) It increases with the amplitude of the vibrations of the sounding body. (3) It depends on the density of the air in the place of production. (4) It is modified by the motion of the atmosphere and the direction of the wind. (5) It is strengthened by the neighborhood of a sounding body.

The **velocity** of sound varies with the medium in which it is propagated. In air, it travels with a speed of 1,093 feet per second at 0°C., and 760 mm. pressure; and it increases nearly two feet for every degree Centigrade of added temperature. It also depends on the strength of the sound, a violent sound being propagated with greater velocity than a softer one. In gases, the velocity is directly as the square root of their elasticity, and inversely as the square root of their density. The velocity of sound in water is four times as great as in air. In solids, the propagation of sound is more rapid than in liquids, for their elasticity is greater in comparison with their density. In experiments conducted with an iron tube 3,120 feet long, it was found that when a bell was struck by a hammer at one end, two sounds were distinctly heard at the other end. The first was transmitted by the tube with an unknown velocity, and the second by the enclosed air with a known velocity. The interval between the two sounds was 2.5 seconds. From this it was ascertained that the velocity of sound in the tube was nine times as great as that in the air.

Reflection of Sound.—Like light, sound may be reflected, and the laws are the same as those for light. By means of a lamp, find the conjugate focus of a concave mirror. Replace the lamp with a watch and stand at the conjugate focus. In this position, the ticking of the watch will be distinctly heard. An *echo* is the repetition of a sound in the air, caused by its reflection from some opposing surface. Monosyllabic echoes are produced when the reflector is at a distance of 112.5 feet—i. e., the last syllable only is distinguished. At a distance of twice 112.5 feet, two syllables can be distinguished, etc. When the distance is less than 112.5 feet, the incident and reflected sounds are indistinguishable, but the intensity is increased. Sounding-boards are constructed upon the principle of reflection of sound; and the phenomena of whispering galleries, such as exist in the Congressional Library and Capitol buildings in Washington, are due to it. The latter are multiple echoes.

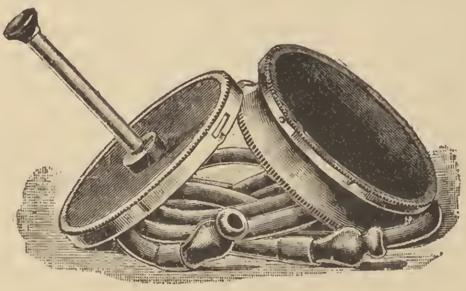
Refraction of sound obeys the same laws as refraction of light. For the experiment, a lens of gas was made by cutting equal segments from a large collodion balloon, and fastening them on the two sides of a sheet-iron ring, a foot in diameter, so as to form a lens about four inches thick in the centre. This was filled with CO_2, and a watch was placed in the direction of the axis. The point on the other side where the watch was heard with greatest distinctness was found, and it was ascertained that if the ear was removed from the axis, the sound was barely heard, but that at a certain point on the axis it was at its clearest.

Transmission of Sound by Tubes.—When a body is made to sound at one end of a tube, the intensity does not decrease in proportion to the square of the distance, because the diffusion of the sonorous waves is prevented, and as a consequence, they are concentrated and transmitted almost unimpaired for quite long distances. Where, however, the tubes are of large diameter, or the sides are rough, weakening is perceptible. Tubes constructed for the transmission of sound are called speaking tubes.

The **ear trumpet** for deaf persons is based on the principle of the concentration of sound waves by a limiting wall. Simply, it consists of a bell, which is an expansion at the end of the tube into which sound is introduced, the other end being introduced into the ear of the affected person.

The **stethoscope** is an apparatus employed for the detection of the various sounds produced in respiration and by the beating of the heart. It consists of an expanded portion, usually of vulcanized rubber, which is placed over the part to be auscultated. In connection with it are two tubes of flexible material, and connected with each of these, in turn, is a curved tube, also of vulcanized rubber, terminating in ear-pieces.

The **phonendoscope** is a modification of Marey's tambor. It "intensifies the audibility of all sounds, whether natural or caused by morbid conditions in the human body." The apparatus "consists of the following parts: A solid metallic rod which collects the vibrations and transmits them to a disc of hard rubber sufficiently strong to withstand the pressure of the rod when it is applied to the body. This disc comes in contact with a second and thinner one, of the same material, capable of vibrating easily. The thin disc is set in a mass of metal the shape and size of a large watch; and between it and the mass is an air space. The thinner, interior disc is the more sensitive of the two; and the stouter one can easily be removed to uncover it. The sound produced by the disc is condensed by the metallic walls of the air space, and carried to the orifices in which are fixed acoustic tubes. These are made of India-rubber which have at one end an olivary ear-tip, the other end bearing a metal tube for insertion in the orifices of the instrument. If, instead of plain metal tubes, forked tubes with several ends are used, a number of persons can at the same time, and with the same instrument, listen to the sounds made by the organ being auscultated." The following precautions are to be observed: When examining the body, contact with clothes or other objects is to be avoided. Press slightly and gradually with the instrument against the part to be examined, in order to secure a direct



The Phonendoscope.

contact. Avoid shocks or undue pressure on the interior disc. Both auricular tubes are always to be inserted in the instrument, even when one tube only is required.

In comparison to the stethoscope, the phonendoscope offers the following advantages: (1) Quick and reliable examination of one or several organs. (2) Possibility of a summary but exact examination, even of dressed persons. In this event, hold the instrument tight to avoid a rubbing at the clothes. (3) Possibility of remaining distant from the patient, which is of considerable hygienic advantage to the physician and more convenient to the patient. (4) Exclusion of disturbances through other noises in the examination room. (5) Possibility of determining the outlines of the or-

The author is indebted to Messrs. GEORGE P. PILLING & SON, Philadelphia, for the use of this cut.

gans and drawing of same on the skin by marking the outlines with a colored pencil.

The phonendoscope offers a certain method of detecting people who feign deafness. Placing the hard rubber tips in their ears, and knocking gently on the rubber disc, let them tell in which ear they hear the noise; then press that tube with thumb and finger without the patient's knowledge; the sound is obstructed and simulation detected.

CHAPTER XXXI.

MEASUREMENT OF THE NUMBER OF VIBRATIONS.

Savart's toothed wheel is an apparatus by means of which the absolute number of vibrations giving rise to a given note can be determined. It consists of two wheels supported in a frame, the larger, when rotated, causing revolution of the smaller toothed wheel by means of a strap and multiplying wheel. In revolving, the toothed wheel strikes against a card and causes it to vibrate, and thus produce sounds. The more rapidly the wheels rotate, the higher becomes the note. An indicator connected with the toothed wheel gives the number of revolutions. Having obtained the sound whose number of vibrations is to be determined, the revolution of the wheel is continued for several seconds at the same velocity. The number of turns is read off, and this, multiplied by the number of teeth in the wheel, gives the total number of vibrations. Dividing this by the number of seconds occupied in turning, the number of vibrations per second for the given sound is obtained.

The **siren** is also an apparatus employed to measure the number of vibrations of a sound in a given time. That of Latour consists of a cylindrical box of brass, closed by a fixed plate, which is perforated by holes at equal distances from each other. On the plate rests a vertical rod, to which is fixed a disc movable with the rod, and perforated by holes equal in number to those of the fixed plate and arranged in a similar manner. The holes are not pierced perpendicularly but obliquely, those in the plate having a direction opposite those in the disc, so that when air is pumped into the box by means of a bellows, the disc is made to revolve. The number of revolutions is read off on dials whose indices are made to move by means of the rod, which has an endless screw. The movement of the screw is communicated to a toothed wheel with 100 teeth, which moves by one tooth for every turn of the disc. A catch on the wheel moves one tooth of a second wheel at each complete revolution. Therefore, the first wheel gives the number of turns of the disc, and the second the number of hundred turns. By means of a screw the revolution of the wheels may be prevented. When the disc is made to rotate slowly, distinct puffs are communicated to the air, but as the movement becomes more and more rapid these blend until a note is formed. To determine the number of vibrations for a given note, the disc is made to revolve until that note is reached. This is kept up for a certain time—say a minute, and the number of turns read off. The number, multiplied by the number of holes in the disc, and divided by sixty, gives the number of vibrations per second.

Limits of Perceptible Sounds.—Helmholtz holds that the perception of sound begins at 16 vibrations, and only has a definite musical value when the number is more than 40. On the other hand, acute sounds are audible up to those of the value of 41,000 vibrations per second. The limits of the perception of sound differ in different individuals.

CHAPTER XXXII.
MUSICAL SOUND.

Sound is the sensation (transmitted through the medium of the ear to the brain) produced by the undulatory motion of bodies when this motion is propagated through an elastic medium.

Sound and Noise.—A musical sound may be distinguished from a noise by the fact that it is rhythmic or periodic, and that it produces a continuous sensation because the vibrations follow one another so rapidly that the ear cannot perceive them separately. A noise is either a sound of too short period to be determined; or it is a conglomeration of many discordant sounds.

Properties of Musical Sounds.—(1) The *intensity* of a sound depends upon the *extent* of the vibrations, being greater when the extent is greater. (2) The *pitch* of a musical note is determined by the number of vibrations per second producing it. It may be determined either by Savart's toothed wheel or the siren.

Musical intervals may be defined as the difference of pitch between sounds in respect to depth or height; or the distance on the staff from one to another in opposition to the unison, which is two sounds of exactly the same pitch. Hemholtz's modification of the siren consists of two boxes each with its movable disc, and perforated by four series of holes, with a corresponding series in the discs. In the lid of one box and in its disc, the circles contain from without inwards, eighteen, twelve, ten, and eight holes, respectively. The upper box has four circles of sixteen, fifteen, twelve and nine holes each. The tubes of the boxes form a common pipe through which air is forced by a bellows. Each circle is provided with a stop, so that each box may be made to communicate a different number of vibrations to the air at the same time. If the upper box is communicating double the number of vibrations that the lower one is, the note produced is the same, but the pitch is twice as high. With the middle C of the piano as the *tonic* or key note, which is due to 264 vibrations per second, the note twice as high is produced by 528 vibrations per second, and that note is called the octave. Taking the scale, from C to D is a second; from C to E, a third; from C to F, a fourth; from C to G, a fifth; from C to A, a sixth; from C to B, a seventh; and from C to c, the octave or eighth, or the beginning of another series. When fifteen holes of one box and twelve of the second are communicating their vibrations, a third is recognized. This is expressed by saying that a fifth is 3-2 of the tonic.

The number of vibrations corresponding to the various notes, with their intervals, are given in the following:

	C	D	E	F	G	A	B	c	
(ut)	do	re	mi	fa	sol	la	si	do	(ut)
	264	297	330	352	396	440	495	528	
	1	9-8	5-4	4-3	3-2	5-3	15-8	2	

The intervals between the successive notes are

C to D	D to E	E to F	F to G	G to A	A to B	B to c
9-8	10-9	16-15	9-8	10-9	9-8	16-15

The three kinds of intervals are 9-8, 10-9, and 16-15; of these, the first two are called a *tone;* the last, a *semitone*, because it is about half as great as the intervals of a tone.

Interference of Sound.—Two sound-waves proceeding in the same direction and coinciding in their condensations and rarefactions, strengthen one another and produce an intensification of the sound. If, however, they differ by half a wave-length, they are in opposite phases, and the condensation of one will coincide with the rarefaction of the other, producing a neutralization, and silence results. This is called *interference*.

Beats.—If the notes are different, and are not quite in the same phase, they alternately strengthen and weaken each other, because condensations and rarefactions alternately coincide and are opposed. To this intensification and diminution of sound has been applied the term *beats*, and they represent the difference between the number of vibrations of the two notes.

Dissonance.—The beats produced by two notes are not perceptible unless the proportion between them is less than 6:5. If the notes vary greatly in their intensities, the intensity of the beat is hidden to a great extent. When the beats are fewer than ten, or more than seventy per second, they are disagreeable, but do not produce discord. With the first number the ear distinguishes each beat separately. Between ten and seventy beats per second, there is entire discord, the maximum of dissonance being reached when about thirty-three beats are produced in a second. This would occur when C and D were sounded together. The effect of beats on the ear, when they become fused, is like that produced on the eye by a flickering light.

Differential Notes.—When two simple notes are sounded together, they generate a series of other notes, the principal one being called the *differential.* It has been called the *grave harmonic*, because its pitch is much lower than either of the notes giving rise to it. Helmholtz showed it was not due to beats, by the existence of differential tones for intervals that do not beat; and by the fact that, sometimes, both the beats and the differential tones may be heard together.

(3) The *quality*, or *timbre*, or *color* of a note is the peculiar property which distinguishes it, when produced by one instrument, from the same note when sounded by another.

Harmonics.—When any note is struck on a piano, or any other instrument, not alone that note is heard, but a series of notes, each of which is of less intensity than the one preceding it. If the *primary* note be denoted by 1, the series is given by the numbers 1, 2, 3, 4, 5, 6, 7, etc. These secondary notes are called the *harmonics* of the primary note, and with it form a *compound* note. This could be graphically represented by drawing curves of the simple notes of different intensities, and taking their algebraic sum. The resulting curve will have a form varying according to the presence or absence of different harmonics. It is readily seen that the quality of the notes produced by different instruments is determined by the *form* of the vibrations producing the sound.

CHAPTER XXXIII.

VIBRATIONS OF STRINGS AND OF COLUMNS OF AIR.

Vibrations of Strings.—A string for a musical instrument is made of catgut or steel wire. The vibrations may be transverse or longitudinal, but usually the former occur.

Nodes and Loops.—If a string, fastened at both ends, be pulled transversely at its centre and let go, it will vibrate its whole length. If it be damped at the centre by a finger or a stop, and then plucked midway of one of its halves, it will vibrate in two parts, the centre remaining motionless even if the stop be removed. Similarly, if it be at a third of its length, and then plucked midway of the third, it will vibrate in three parts, two points remaining motionless, etc. The vibrating portions of the string are called *loops* or *segments;* the motionless points *nodes*.

When a note is sounded by striking a string, it is not a simple one; for partial vibrations or *overtones* are soon produced and added to it. These correspond to the various segments, and give rise to harmonics. Dissonance may be produced by the harmonics when the fundamentals are too far removed to produce audible beats.

Wind instruments are divided into mouth and reed instruments. When their sides are of sufficient thickness, the enclosed column of air is the sonorous body.

In **mouth instruments** all parts of the mouth-piece are fixed. The aperture is called the mouth, and through it air enters the pipe to impinge against one of the lips, the upper of which is bevelled. A rapid current of air, entering the mouth, strikes the upper lip, producing impulses which emerge intermittently through the aperture between the lips. The pulsations are communicated to the air within the pipe, and a note results. The number of vibrations is determined by the area and length of the pipe and the velocity of the current of air.

Reed instruments have an elastic tongue, which sets the air to vibrating. The tongue, which is moved by a current of air, is fixed by its upper end, and either moves in and out of a longitudinal aperture, or is larger, and strikes against its edges at each oscillation, closing it like a flap.

The column of air contained within a pipe possesses nodes and loops. At the nodes are rapid alternations of condensation and rarefaction; while in the loops, which are sections of the column, the vibrations make their greatest excursions, and there is no change of density. If, into a pipe sounding a note, a membrane sprinkled with fine sand be lowered, it will be set in vibration which is at its greatest when a loop is reached. At a node, however, there is no agitation of either membrane or sand, for here there is no vibration, as the air is at rest.

CHAPTER XXXIV.

CONSONANCE AND RESONANCE.

Consonance, or **sympathetic vibration,** is the property possessed by a sounding body of selecting the tone being produced by a second body, and vibrating in unison with it. If two tuning-forks, tuned for the same note, be at some distance apart, and one be struck, after an interval, the second will vibrate and emit the same note. The condensations and rarefactions of the first fork strike against the second, and, though each is too feeble to set it vibrating, the successive action of the series of impulses finally does so.

Resonance is the reinforcement of sound produced when a sonorous body is attached to a sound-board, or to a hollow wooden box, called a *resonator.* It begins and ends with the sound of the exciting body. In order that a body may act as a resonator, its length must bear a certain relation to the vibrations of the sounding body. If a tuning-fork be struck and held over the mouth of a cylindrical jar which is being noislessly filled with water, there comes a time when the sound, at first inaudible near by, will be heard at some distance off. To produce the greatest effect, the length of the column of air in the jar must be one-quarter the length of a vibration of the fork. A wave-length consists of a condensation and a rarefaction. When the limbs of the fork move outward, the former is produced; and when they return to their position of rest, the latter. The condensation travelling through the air of the jar must pass downward, be reflected by the water, and return to the orifice as the outward movement of the fork is completed and the rarefaction begun, in order to be in harmony with it. The condensation is half a wave-length, and it moves through the air in the jar upward and downward. The length of the column of air is then half of a condensation, or a quarter of a wave-length.

Resonators.—The sound of a tuning-fork caused to vibrate, cannot be heard unless the instrument be held close to the ear. If, however, the stem is held on a table, the note becomes louder. As a usual thing, forks are mounted upon boxes of such length that the column of air within vibrates synchronously with the note of a particular fork, but with no other, and the sound is rendered audible to persons at a distance from it. If the box is open at both ends, its length must be that of half a vibration of the note it is to reinforce; and a quarter, if closed at one end. This is one form of a resonator.

Hemholtz's *resonance-globe*, another form of resonator, consists of a glass globe (tuned to a particular note), furnished with two openings, the larger being turned towards the origin of the sound, the smaller applied to the ear through the intervention of a rubber tube. If this instrument is held to the ear during the performance of some piece of music, it will pick out the note to which it is tuned, and the listener will hear it with great distinctness; but it will resound to no other note. Koenig's modification of the resonance-globe is cylindrical. It being possible to draw out the end which receives the sound, the volume may be increased at will; and the sound becoming deeper, the same instrument may be tuned to many notes. Analysis of sound has been rendered possible by the employment of a number of these resonators.

Organ pipes are resonators. Stopped pipes must be one-quarter the wave-length of a given vibration in order to reinforce the sound; while open ones require to be one-half the wave-length.

Perception of Sounds.—The ear is the organ of hearing. The human auricular appendage is immovable, but the various projections and depressions act so as to finally reflect sound into the *external ear*. At the end of this they impinge against a membrane, the *tympanum*, which is made to vibrate. The tympanum, separating the external from the *middle ear*, is connected with a series of three ossicles stretched across the latter, and when it vibrates the ossicles are made to do so likewise. In the *internal ear*, which is a complicated structure, is a fluid bathing the terminals of the *auditory nerve*, which are about 3,000 in number. The innermost of the ossicles is attached to a membrane which closes one of the openings of the internal ear. When the ossicles vibrate, the movement is communicated through the membrane to the fluid, and then to the nerve terminals, which are called the *organs of Corti*. Each of these, it is generally supposed, seems to act like a resonator, picking out a particular note which is perceived by the centre of hearing situated in the brain.

Production of Vocal Sounds.—The *larynx* is the true organ of the voice. It is a cartilaginous box, across which run two *vocal cords*. These may be approximated or separated, be made tense or relaxed, by the action of certain muscles. They act the part of reeds, and by their vibrations, break up into separate puffs the stream of air as it issues from the lungs. This is vocalization. That part of the larynx above the cords, and the pharynx, mouth and nose act as resonators, and give quality to the voice. In *women* as compared with *men*, the cords are shorter, and the notes, therefore, of higher pitch. The voice of boys is akin to that of women. Each vowel sound may be produced when the cords are sounding the same fundamental note. The difference in them arises in the form given to the mouth. *Chest notes* are produced by vibration of the entire length of the cords; *falsetto notes* by vibration of the extreme edges of only a part of the length.

HEAT.

CHAPTER XXXV.
THE NATURE AND SOURCES OF HEAT.

Nature of Heat.—(1) The *emission theory* supposed that there was an imponderable fluid surrounding the molecules of bodies, and capable of passing from one to another. In doing so, these *heat atmospheres* exerted a repulsive effect on each other, and produced, in consequence, a change of state. The substance, also called *caloric*, entering a person, produced the sensation of warmth; and leaving it, the sensation of cold. (2) The *undulatory theory*, now accepted, supposes heat to arise from extremely rapid molecular vibration, the hottest bodies being those in which the molecules are vibrating most rapidly and to the greatest extent. The oscillations are conveyed from one body to another by the luminiferous ether setting the molecules of the second body into more rapid vibration, and thus increasing its temperature.

Dynamical Theory.—According to this, mechanical energy is capable of being converted into heat, and *vice versa*. The truth of the first part of this is seen in various occurrences—viz., the production of heat by friction, hammering of metal, etc.

The **mechanical equivalent** of heat, or the relation between mechanical energy and heat, was established by Joule, who found that a weight of 1 pound, falling through a height of 772 feet, generated enough heat to raise the temperature of 1 pound of water 1° F. 772 foot-pounds was the amount of work done. The *thermal unit*, or *heat unit*, is the amount of heat necessary to raise 1 pound of water 1° F., and it is equal to 772 foot-pounds of mechanical energy.

Sources of Heat.—(1) Mechanical work. All other forms of energy can be converted into heat. (2) Chemical combination always produces heat, and, if the amount is sufficient, combustion occurs with the formation of light. Oxidation of a substance is always accompanied by the evolution of a certain amount of heat, no matter whether the oxidation occur rapidly or slowly. Various foods, by being oxidized within the body, give rise to heat. (3) The sun is the greatest source of heat—directly, by its rays, and indirectly, by the burning of fuel in which the sun's energy is stored. The combustion of a pound of coal represents the daily work of an adult man. The heat of the sun is equal to that produced by burning, every day on the surface of the earth, a globe of coal weighing sixteen tons.

CHAPTER XXXVI.

TRANSMISSION OF HEAT.

Heat may be transmitted by (1) conduction, (2) convection, (3) radiation.

(1) **Conduction** of heat is that method whereby this form of energy is conveyed from one portion of a body to another by movement of its molecules. If the end of a poker be thrust into a fire, very soon, not only will that end become warm, but the heat will be felt at the other end also. All substances do not conduct heat in equal degree. Metals are the best conductors; while stones, glass, resins, wood, feathers, hair, wool, etc., offer a greater or less resistance to the transference of heat. The conductivity of liquids and gases is very small.

The *coefficient of thermal conductivity* is the quantity of heat that passes in a second of time between the two opposite faces of a cube of the substance one centimetre thick, and which are kept at a constant difference of 1° C.

The **practical applications** of the conductivity of bodies are seen frequently. A liquid can be kept warm for some time, if the vessel containing it is surrounded by a bad conductor, as shavings. Ice can be prevented from melting by wrapping it in flannel, etc. Danger of breaking a glass vessel, when subjecting it to heat, is overcome by interposing between it and the flame a piece of asbestos. Stone is a better heat conductor than either wood or brick. The two latter are, therefore, better suited for building purposes. Wood is especially advantageous. Animals are protected from the influence of cold by their wool, hair, feathers, etc. Clothing protects, not because of any warmth of itself, but because it hinders the escape of the body-heat. It also prevents the passage of heat inward. In summer, therefore, wool, which is a very bad eonductor, is rcplaeed by linen and cotton, whieh are better eonductors. That two bodies of the same temperature convey different ideas of heat to the touch is due to their eonduetivities. A pieee of wood will not feel as hot as a pieee of iron, beeause the latter is the better conduetor. If both have the same degree of eoldness, the iron will appear to be the colder of the two. The closer a substance is held, the greater is the amount of heat felt; and with smooth surfaces, there are more points of contact than with rough ones, so that they convey more heat.

(2) **Convection** of heat is its transferenee by aetual movement of heated partieles from one plaee to another. In this manner, masses of liquid and gas are heated. Currents of water and the trade winds are brought about through this agency; and ventilation were not possible without it.

(3) **Radiation** is the transferenee of heat through a medium without raising the temperature of that medium. On a cold day, when standing in the sun, one feels its warmth, but the surrounding air remains cold. Standing in front of a fire, one experiences a sensation of warmth, not due, however, to the temperature of the air, because if a sereen be interposed, the sensation disappears, which would not be the case if the air had a high temperature. Unlike sound, radiant heat can be propagated in a vacuum. Air, therefore, is not neeessary for it, and, as in the ease of light, it is held to be due to vibrations of a universal, luminiferous ether; but its undulations are longer and slower. Like light, it is both reflected and refracted. The ultra-red of the spectrum is rich in heat rays.

Heat Radiation and Absorption.—A substance that reflcets heat to a great extent, will absorb it inversely. A body that absorbs heat well, will radiate it, but not in exactly the same proportion. Metals have the greatest reflecting power, and lampblack the least. Certain substances are opaque to heat rays, i. e., absorb them, and beeome heated; others transmit them, are transparent, and remain unaffected. The former are said to be *athermanous*—water, alum; the latter, *diathermanous*—rock salt, bisulphide of carbon.

The *application* of these facts is frequently witnessed. The principle that white substances reflect heat very well, and absorb very little, and that the reverse is true of black substances, does not hold absolutely. White lead absorbs heat rays as well as does lampblack. Varnish causes great radiation—so much that an animal coated with it soon dies, being, one may say, frozen to death. The principle stated does not, however, apply to substances that absorb powerfully, as cotton, wool, etc., when exposed to luminous heat. The color of clothing most suitable for summer wear, therefore, is that which experience has taught us, viz., white. A black kettle cools faster than a bright, metallic one. Steam-pipes of locomotives should be kept bright, for the same reason. The outsides of stoves, and hot-water apparatus for heating houses, should be black; and firebrick should line the interior of fireplaces to increase the radiating power.

Bodies can be employed to sift the light from the heat rays. Rock salt covered with lampblack or iodine, transmits heat, but stops light; and alum is transparent to light, but opaque to heat. The ultra-red rays have been demonstrated by focussing the rays of an electric light with a concave mirror. In the path of the beam was placed a cell containing a solution of iodine in bisulphide of carbon, which is opaque to light but transparent to heat. In the focus of the beam a piece of platinum was placed, and soon rendered incandescent.

CHAPTER XXXVII.

EXPANSION.

Expansion of Solids.—Generally, heat has the effect of (1) raising the temperature of bodies; (2) producing increased amplitude of molecular vibration, thus increasing the size of bodies, or completely altering the relative positions of the molecules, thus effecting a change of state; and (3) overcoming external atmospheric pressure.

While expansion of solids is not so great as expansion of liquids or of gases, it may be demonstrated by applying heat to a bar composed of strips of two different metals fastened together at their extremities. As the heating goes on, the strips will separate from each other at the middle, and because they are fastened at their ends, will soon become bowed. This shows the linear expansion of solids. Their cubical expansion is shown by the "ball and ring." The ball, ordinarily, can pass through the ring; but when it is heated it becomes expanded, and in this state cannot be passed through.

Expansion of Liquids.—Liquids expand more than solids, but less than gases; and as they have no definite shape, the change is merely in volume. A bulb, provided with a long capillary stem, is filled with a colored liquid, and heat applied. At first, there is a fall of the liquid in the tube, due to expansion of the glass before the heat can reach the liquid; but the expansion of the liquid soon becoming greater than that of the glass, it ascends. On cooling, the column sinks. Water obeys the common rule of contracting when cooled, till its temperature becomes 39° F.; but after that point is reached, it presents the unusual phenomenon of expanding. At this temperature, therefore, it has its maximum density. In winter, the surface layers of rivers and lakes become cooled and sink to the bottom, to be replaced by warmer layers, which, in turn, become cooled, until the whole has a temperature of 39° F. Soon, the top layers freeze, and the ice formed protects the water below, which remains at 39°, at which temperature life is not destroyed. It is this expansion which causes the bursting of water-pipes, and the cracking of earth, stones, etc.

Expansion of Gases.—For the same amount of heat, gases expand more than do either solids or liquids. The demonstration of their increase of volume may be made also with the bulb and tube. A small amount of a colored liquid is introduced into the tube to serve as an index. When heat is applied to the bulb (that of the hand will suffice), the index is seen to rise. All permanent gases expand to very near the same extent for every degree of increased temperature, and this amount is called the *coefficient of expansion*. Gases increase by 1-490 of their volume for every degree Fahrenheit.

100 cu. in. of gas at 60° F., become what at 85° F.?

490 + 60 : 490 + 85 : : 100 : x.

Isotropic bodies are those whose volume is affected equally in all directions, because their cohesion is equal.

Aelotropic bodies present irregularities when heated, because their cohesive power is not equally distributed.

CHAPTER XXXVIII.

THERMOMETRY.

The **temperature** or **hotness** of a body may be defined as the extent, in either of two directions, to which it will impart sensible heat to other bodies. This is not to be confused with the amount of heat it possesses. Thus, a cupful of hot water taken from a bucketful, has the same temperature as the latter, but it possesses a far less quantity of heat.

Thermometers are instruments employed for the measurement of temperatures. Those used generally, are based on the expansion produced by heat; and, as solids expand little, and gases too much, liquids are best suited for their construction, and those employed are mercury and alcohol, the former boiling only at a very high temperature, the latter not solidifying at the greatest known cold. The *mercurial thermometer* is most generally used. It consists of a capillary glass tube, blown out at the lower end into a bulb with very thin walls. The whole is filled with mercury, and the height is measured by a scale situated either on the stem, or on the frame to which it is attached. Filling the thermometer is accomplished by first blowing on its top a small funnel into which mercury is poured. The bulb is then heated so as to cause expansion of the air within it. Some of it escapes through the funnel; the remainder, on cooling, contracts, and a portion of the mercury takes its place. This procedure is repeated until the bulb and part of the tube are filled with the liquid. The mercury being now heated to boiling, its vapors escape and carry along with them the air and moisture remaining in the tube, which is then sealed at its open end. Graduation of the thermometer is accomplished by determining first, what are called the fixed points. The instrument is immersed in a mixture of ice-water, and after a few minutes the point to which the mercury sinks is marked according to the scale used. The boiling point is determined by surrounding the instrument with steam from boiling water, and when the mercury has remained stationary for a time, a mark is made on the stem at its level. Both marks should be obtained at 760 mm. pressure. The tube between the marks is now divided off equally, and the graduation continued both above and below the fixed points.

In Fahrenheit's scale, freezing point is denoted by 32°, and boiling point by 212°. In the Centigrade scale, these points are respectively 0° and 100°; while in Réaumur's scale they are 0° and 80°.

Fahrenheit may be converted into Centigrade degrees by the formula

$$F=9-5\ C+32.$$

Centigrade may be converted into Fahrenheit by the formula

$$C=5-9\ (F-32).$$

Réaumur into Fahrenheit:

$$F=9-4\ R+32.$$

Fahrenheit into Réaumur:

$$R=4-9\ (F-32).$$

Alcohol thermometers are filled with colored alcohol, and are especially suitable for measuring low temperatures.

Aneroid thermometers are constructed in a manner similar to aneroid barometers.

Clinical thermometers have a very fine bore (with a bulb of very thin walls), for a given amount of heat will cause a greater advance of mercury in a fine capillary than in a coarser one. To make the thermometer of convenient length, the scale is marked from 95° to 110°, each degree being divided into fifths. A short distance above the bulb, there is an expansion of the bore, and it is only along the sides of this that mercury can pass when heat is applied to the bulb. There are two columns of mercury—one in connection with that contained in the bulb; the other above the expansion, and called the index. After the thermometer has been removed from the body, the index remains stationary; for unless the instrument is shaken, it cannot pass beyond the expansion. Such a thermometer is said to be *self-registering*.

CHAPTER XXXIX.

PRODUCTION OF CHANGES OF CONDITION BY HEAT.

Fusion.—When heat is applied to a solid for a certain length of time, cohesion is overcome and the body passes into the liquid state. This is called *melting* or *fusion*, and the temperature at which it melts is called the *melting point* or *point of fusion*. Increase of volume generally occurs upon liquefaction, except in the case of water, cast-iron, bismuth and antimony.

Laws.—(1) Every substance begins to fuse at a certain temperature, which is invariable for that substance if the pressure be constant. (2) Whatever the intensity of the source of heat, from the time fusion begins, the temperature of the body ceases to rise, and remains constant until fusion is completed.

Latent Heat.—As the temperature of a body remains constant from the time it begins to melt till fusion is completed, it must absorb a considerable amount of heat, and this is called the *latent heat of fusion*. A mixture of a pound of water at 80° C. with a pound at 0° C., will have a temperature of 40° C. A mixture of a pound of cracked ice at 0° C. with a pound of water at 80° C., will result in two pounds of water at 0° C. Therefore, to melt a pound of ice to form a pound of water having the same temperature, requires as much heat as to raise a pound of water from 0° C. to 80° C. The latent heat of water is 80. Expressed according to the Fahrenheit scale, it is 142 (174—32). When a solid is simply dissolved in a liquid, heat becomes latent, with a consequent diminution of temperature.

Solidification is the passage of a body from the liquid to the solid state, and is governed by the following laws:

(1) Every body, under the same pressure, solidifies at a fixed temperature. (2) From the commencement to the end of solidification, the temperature remains constant.

Latent heat, absorbed during fusion, becomes free at the moment of solidification. When water contains a salt, its freezing point is lowered in proportion to the weight of salt dissolved. For this reason, sea-water requires a lower temperature for solidification than fresh water.

Superfusion.—The freezing point of a pure liquid can be lowered several degrees if it be previously freed from air by boiling, and be then kept perfectly still. A liquid solidifies very rapidly after being cooled below its normal freezing point, the solidification being accompanied by an evolution of heat sufficient to raise the temperature from the point at which it began, up to its ordinary freezing point.

Freezing Mixtures.—The fact that heat is rendered latent by liquefaction, has been utilized in the production of artificial cold. The bodies employed must have an affinity for each other, and one at least must be solid—as water and a salt, ice and a salt, or an acid and a salt. Chemical affinity hastens the fusion. Some ice machines operate upon this principle—one portable form using sulphate of sodium, 8 parts by weight, and hydrochloric acid, 5 parts by weight. This will make five to six pounds of ice in an hour.

Vaporization is the passage of a liquid into the gaseous state. Like gases, vapors are elastic and exert pressure on the sides of the vessels containing them. Ordinarily, vaporization goes on slowly, but in a vacuum there is no resistance, and it occurs instantaneously with a volatile liquid. At the same temperature, the vapors of different liquids have different pressures. That of ether at 78° F. is twenty-five times as great as that of water. There is a limit to the quantity of vapor that can be formed in a given space at a certain temperature. When this has been reached, the vapor is said to be *saturated;* and in this condition it differs from gases, for it can neither be compressed or expanded. When it is unsaturated, however, it exactly resembles them. Evaporation occurs from the free surface of the liquid only. It may occur even below freezing point, shown by the drying of linen that has been wet and exposed to the air during frost.

Acceleration of evaporation occurs with (1) increase of temperature, (2) diminution of the vapor already present in the atmosphere, (3) renewal of the atmosphere, and (4) extent of the surface of evaporation. Vegetation, in its period of growth, increases the amount of evaporation.

Ebullition, or *boiling*, is the condition in which there is formation of bubbles of vapor within the mass. When a liquid contained in a glass vessel is heated, the first bubbles are formed from air which has been previously absorbed. Small bubbles soon begin to rise from the heated sides; but, as they pass through the cooler upper layers, they become condensed and collapse, giving rise to the singing or simmering heard before a liquid begins to boil. Later, however, large bubbles rise to the surface and burst, and this constitutes boiling.

Laws.—(1) The temperature of the boiling point increases with the pressure. (2) For the same pressure, the temperature is always the same for a given liquid. (3) The temperature of the liquid remains stationary as soon as boiling begins.

Retardation of ebullition occurs when the liquid contains in solution a substance not more volatile than itself. Water boils at 212° F.; water saturated with common salt, at 249° F. Substances merely suspended do not affect the boiling point.

The nature of the vessel has an influence on the boiling point. Whereas in a copper vessel, that of water is 212° F., in a glass vessel it is 230° F. A piece of metal in the bottom of a vessel containing fluid, will always lower the boiling point, and prevent the violent concussions attendant on the boiling of saline or acid solutions in glass vessels.

Influence of Pressure on the Boiling Point.—Under a pressure of 30 inches, water boils at 212° F. Aqueous vapor has a tension equal to that pressure, or, in other words, a liquid boils when the tension of its vapor equals the pressure it supports. Increase or decrease of pressure causes an increase or decrease of the boiling point. For this reason, water boils at a lower temperature on high mountains.

Papin's digester consists of a cylindrical iron vessel fitted with a cover which is tightly screwed down, sheet lead being placed between the edges of the two to close the vessel hermetically. In the cover, is a small hole in which there is a rod. A movable lever fastened at one end to the cover screw, and having at the other end a movable weight, presses down the rod which acts as a valve. When the internal pressure rises to a certain number of atmospheres, the valve forces up the lever, allowing the vapor to escape. Because it prevents destruction of the apparatus, it is called a safety-valve. By this means, the temperature of the water being boiled, may be raised far above 212° F., and the pressure of the vapor increased several atmospheres. The apparatus is used in extracting gelatine from bone.

The *latent heat of vapor* is the quantity of heat absorbed in the transition from the liquid to the gaseous state. It requires as much heat to vaporize a pound of water as would raise a pound of water through 607° C., or 607 pounds of water through 1° C.

Applications.—The absorption of heat during vaporization is taken advantage of in surgery for the production of local anesthesia. Ether, or some other volatile liquid, is sprayed upon the site of operation, the tissues become frozen, and section can then be made. The manufacture of ice on a large scale is an application of the same principle.

The Dew Point.—If the atmosphere has absorbed a certain amount of aqueous vapor, an increase of temperature will favor further absorption. If, now, there should be a fall of temperature, vapor, in the form of dew, will be deposited.

Liquefaction of vapors and gases may be produced by cooling, compression or chemical action.

Distillation is the method by which a volatile liquid may be freed from substances it holds in solution; or two liquids of different volatilities may be separated. It depends on the formation of vapor by heat, and the condensation of the vapor by cooling.

The apparatus used is called a *still*, and consists of three parts—the *body*, a copper vessel containing the liquid and fitting on a furnace; a *head*, fitting on the body and provided with a lateral tube which leads to the *worm*, a long spiral or copper tube kept constantly full of cold water. Ordinary water, to be made pure, is placed in the still and heated. The vapors formed are condensed in the worm, and the distilled water produced by the condensation is collected by a receiver. The rapid condensation heats the water in the cistern. This is constantly renewed by a continual supply of cold water which enters at the bottom of the cistern, the lighter, heated water rising to the top and escaping by a tube placed at that point.

The Spheroidal State.—When water is dropped on red-hot metal the liquid does not moisten it and then boil away, but it assumes a spherical form and tumbles and rolls about. The water is separated from the metal by a cushion of steam. As soon as the metal cools sufficiently, steam ceases to form, and the water comes in contact with the metal and boils away. Because of this condition, the hand may be plunged in melted lead or iron. Radiant heat is expended in the formation of aqueous vapor on the surface of the hand and prevents the metal from touching it.

CHAPTER XL.

SPECIFIC HEAT. CALORIMETRY.

The thermal capacity of a body is the amount of heat necessary to raise it through one degree Fahrenheit.

The specific heat of a body is the amount of heat necessary to raise it in a certain interval of time to a certain temperature, as compared with the same circumstances in a standard body. Water being the standard used, it may also be defined as the ratio between the quantity of heat necessary to increase the temperature of a body one degree, and that necessary to raise the same quantity of water one degree.

Two bodies at the same temperature will evolve different amounts of heat because of their different specific heats.

Calorimetry is the measurement of the quantity of heat given out or absorbed by a body when it changes its condition, or its temperature decreases or increases.

Calorimeters are the instruments employed for this purpose. The amount of heat given out by a body can be measured by the quantity of water whose temperature it will raise one degree, or by the number of degrees it will raise a unit mass of water. Sources of error can creep in a measurement performed in this manner, because heat is given off in other ways than to water, thus causing its loss. The *water calorimeter* consists simply of a vessel filled with water, and surrounded by a non-conducting material. The hot body is plunged into the water, and the difference in temperature before and after this gives the amount of heat gained by the water. The *ice calorimeter* consists of a cylinder of copper in an outer vessel containing broken ice at the melting point. The heat of the body melts the ice, and is measured by the quantity of water produced. A third vessel, also containing broken ice, surrounds the others.

CHAPTER XLI.

ANIMAL HEAT.

Sources of Animal Heat.—(1) Chemical action. The main source of animal heat is the oxidation going on within the body during both activity and repose. The food stuffs within the body are attacked by oxygen and reduced. Nitrogenous matters are not fully oxidized, the process stopping with the formation of urea. Not only does food undergo this change, but the air breathed, also. It is really a form of combustion. This chemical action, however, does not appear wholly as heat, a portion showing itself as mechanical energy, except during repose. (2) The amount of heat due to mechanical work cannot be well estimated; but that it is produced, is very evident.

A special form of calorimeter has been constructed for the estimation of the amount of heat liberated by an animal in a given time.

Regulation of Animal Heat.—Animal heat is regulated by variations in A, Heat production, and B, Heat loss.

Loss of heat occurs (1) from the surface of the body by (a) conduction, (b) radiation, and (c) evaporation. This last means extracts more heat than the others, for the perspiration in passing from the liquid into the gaseous state, absorbs a large amount of this form of energy. (2) From the lungs. While the amount of heat lost thus is not inconsiderable, especially when the number of respirations is increased, it cannot be compared to that lost from the surface of the body. (3) Warming cold food and drink. (4) In the excreta.

While animals are naturally protected to a great extent from climatic conditions, the human being resorts to clothing to accomplish the same end. For this reason, apparel should receive proper attention. Previous statements demonstrate that, though color does not affect the radiating power, dark clothing absorbs heat to the greatest extent. Rough material radiates more freely than does smooth. The absorptive power of cloth should also be considered, since upon it depends the sucking up, as it were, of moisture from the skin, and the consequent loss of a large amount of heat. In warm weather, material of loose texture is to be preferred to that more closely woven, for the reason that convection can go on more freely.

CHAPTER XLII.

MATTER. FORCE. MOTION.

Dynamics deals with the laws regarding the action of force upon matter, whether solid, liquid or gaseous.

Matter, as has been defined, is anything that exists, or rather, that which possesses properties made known to us by our senses.

Having considered dynamics as applied to liquids and gases, we shall now briefly study the relation to solids.

Measure of Space.—Space may be either *length* or *distance*, which is space of one dimension; *area*, of two dimensions; or *volume*, of three dimensions. The English and American linear standard is the yard; the unit, however, being the foot, which is one-third of a yard. The French standard is the metre, which is about a ten-millionth part of the earth's surface between the equator and the north pole. 1 metre = 10 decimetres = 100 centimetres = 1,000 millimetres. 1 kilometre = 1,000 metres. 1 metre = 39.37 inches. 1 kilometre = 39,370.432 inches or nearly 10,936 yards. 1 millimetre = 1-25 inch, about.

Measure of Mass.—Mass is the quantity of matter—that amount that remains the same throughout all changes which the body may undergo. The English and American unit is the pound avoirdupois, equal to 7,000 grains. One pound troy contains 5,760 grains. The French standard is the kilogramme which is the weight of a cubic decimetre of water at 4° C. It contains 1,000 grammes, a gramme being the weight of one cubic centimetre of water at 4° C. One gramme is equal to about 15 grains.

In the metric system, volume is cubic mass. A litre is equal to 1,000 cubic centimetres.

Measure of Time.—The second, which is the 86,400th part of a mean solar day, is the unit of time.

Measure of Velocity.—Velocity is the rate of motion of a body. It may be *variable*, when the body passes through unequal portions of its path in any equal times; or *uniform* when the body passes through equal portions in all equal times. The path, or continuous line described, is sometimes called the trajectory. Uniform velocity is measured by the number of units of space passed through in a given time, the units employed being feet and seconds. When a velocity of say 6, is spoken of, it means a velocity of 6 feet per second. Therefore, when a body moves for a certain number of seconds with a uniform velocity, the space described is the velocity multiplied by the number of seconds. Variable velocity is measured at any instant by the number of units of space described by a body, if its motion continued uniform from that instant for a unit of time.

Force is defined as "whatever changes, or tends to change, the motion of a body by altering either its direction or its magnitude."

Newton's Laws.—(1) A mass of matter at rest, will reremain at rest unless set in motion by an external force.

(2) A mass of matter in motion will remain so, and move in a straight line unless acted upon by an external force.

Two forces are equal when they act on two equal masses and impart to them equal velocities. Velocity is determined then not only by the force acting and the time during which it acts, but also by the mass of the body.

Mass and weight must not be confounded. Thus a pound is the unit of mass, but the weight of a pound is a force. At the centre of the earth mass has no weight.

Measure of Force.—(1) Absolute method. Force can be measured by the velocity given to bodies. If two bodies are acted upon by two unknown forces, and the velocities imparted are identical, the forces are equal. If one move twice as fast as the other, one force is twice as great. *Momentum* is mass multiplied by velocity; so that it may be said that force is measured by the change in momentum it can produce per second. (2) Gravitation method. A pound mass is attracted towards the earth with a certain force, a two-pound mass with twice that force, etc. This force differs at different places. The force with which the earth attracts a pound of matter is capable of imparting to the pound an acceleration of 32 feet—i. e., if the pound were allowed to fall freely, it would move through a distance of 32 feet per second. A pound mass then, produces 32 units of force for, as has been said, force can be measured by the velocity produced in a unit mass in unit time.

Dynamometers are instruments for measuring force. One form consists of two steel bows connected at their extremities. Attached to the upper bow is a ring for suspension of the apparatus, and attached to the lower bow is a hook, to which is fixed the force to be measured. Between the bows is a scale in two parts, which slide on one another. The distance of separation of the bows produced by the force is measured by the scale.

Representation of forces is made graphically by straight lines, the length of the lines being proportional to the magnitude of the forces acting.

Resultant and Components.—A point remaining in equilibrium, when acted upon by several forces, does so because one of the forces neutralizes the combined effects of all the others. Say that a mass is being acted upon two forces, one pulling obliquely to the right and the other to the left. A third force is introduced, whose pull is directly upward, and whose effect is to neutralize the effect of the other two. If, now, the third force has its direction reversed, the effect produced would be that of the others. This force is called, therefore, the *resultant;* the others, the *components*

Parallelogram of Forces.—If two forces act on a point, and lines be drawn from that point representing the forces in magnitude and direction, and a parallelogram be constructed on these lines as sides, their resultant will be represented in magnitude and direction by that diagonal which passes through the point. In the same way the resultant of several forces may be found. The diagonal and the third force are used to construct a second parallelogram whose diagonal is the resultant of the three forces, etc. The *composition of forces* is the process of finding a single force which can be substituted for several. The *resolution of forces* is decomposition of a single force into two, etc.

Resultant of Parallel Forces.—If two forces act on a rigid bar in the same direction, the resultant will be equal in magnitude to their sum; and if they are equal forces, they may be replaced by the resultant force midway between them. If they are unequal, the point of application will be nearer to the greater force; or, in other words, the point of application of the resultant is at a distance inversely proportional to the magnitude of the forces. The *moment of force* is the product of the force multiplied by the distance between its point of application and the resultant.

If two equal and parallel forces act in opposite directions on a rigid bar, there will be no resultant. This is called a *couple*, and the movement produced is one of rotation. But two unequal parallel forces can be reduced to a single force acting in the direction of the greater force, and equal in magnitude to the difference between the two forces.

Action and Reaction.—Reaction is always equal and contrary to action. This is true of bodies both in motion and at rest.

Centrifugal Force.—According to the first law of gravity, a mass of matter in motion will remain so and move in a straight line unless acted upon by an external force. If a body moves in a circle, it must be because some uniform force causes it constantly to deviate from the straight line. This is seen in the sling-shot. If the string be cut, the stone moves in a straight line with the velocity it already has. The tension of the string which pulls the stone toward the centre, and gives it its circular motion, is called the *centripetal* or *central* force; the reaction of the stone upon the string, equal and opposite to this force, is called the *centrifugal* force. It is applied in the separation of sediments from urine, of corpuscles from blood, bacilli from sputum; and, in chemistry, in the separation of crystals from the mother-liquors.

CHAPTER XLIII.

LEVER. PULLEY.

The lever is a name applied to any bar, straight or curved, resting on a fixed point or edge, called the *fulcrum*. The forces acting on the lever are the *weight* or resistance, the *power*, and the reaction of the fulcrum. Levers are applications of the principles of parallel forces, and are divided into three classes or orders: (1) In levers of the first class, the fulcrum is between the power and weight. It has the advantage that, if the arms are properly fixed, a small power may be made to move a large weight. (2) In levers of the second class, the weight is between the power and the fulcrum. The power acting through a longer arm than the weight, again has the advantage, but it must move through a greater distance. (3) In levers of the third class, the power is between the weight and the fulcrum. While here, power is at a disadvantage, the weight moves through a greater distance with a small expenditure. It is a lever of velocity.

Pulleys are of two varieties—fixed and movable. In the case of the fixed pulley, if the power and weight are equal, there is equilibrium. Therefore, it gives no advantage, but affords convenience in that it changes the direction of pull.

In a simple movable pulley, one end of the rope is fixed to a hook, is then passed around a single pulley to which is attached the weight, and then around a fixed pulley. Power is applied to the free end. The fixed pulley is merely for changing the direction of pull. The pull on the rope is everywhere the same. One portion of the weight is supported by the fixed part and the other by the power. These two are equal to each other, and are, together, equal to the weight. In other words, if the hook is pulled on with a force of one pound, the weight is pulled up with a force of two pounds. But because of the rope being doubled, the weight moves only half the distance the power does. If a block and tackle, which is a system of pulleys, be used, the power necessary to raise the weight will be diminished, but the distance through it which it must pass to do so, will be increased.

CHAPTER XLIV.

GRAVITY. THE BALANCE.

Gravity is the force with which a mass is attracted toward the earth. This is terrestrial gravitation, and is an example of universal attraction. *Gravitation* is the movement toward the earth. *Weight* is the force with which a body is attracted; and mass, as has been said, is the real quantity of matter, upon the number of its particles, depending the force of gravity, and therefore weight. The direction of gravity at any point of the earth's surface, is called the *vertical* line, and is determined by the plumb line, which is a weight hanging freely from the end of a string.

Newton's Law.—The attraction between the bodies is directly proportional to the product of their masses, and inversely proportional to their distance apart.

The **centre of gravity** of a body is the resultant of the forces of attraction between the molecules of that body and the earth; and, according to its form, it is situated within or without the body. It may be determined for a body by suspending it from one point by a string which is prolonged and has a small weight attached. This gives one vertical. Next, suspend it from another point and obtain the second vertical. Where the latter crosses the first vertical is the centre of gravity, provided the density of the body is uniform.

Equilibrium of heavy bodies is established when the centre of gravity is balanced by the resultant of other forces and resistances, acting on the body at the fixed point through which it passes. If a body is fixed by only one point, equilibrium exists when the vertical through the centre of gravity passes through that point. If it is supported by more than one point, equilibrium exists when the vertical passes through a point within the space formed by the points of support.

States of Equilibrium.—(1) *Stable equilibrium* is said to exist when a body returns to its original position after having been disturbed. In this state, the least movement raises the centre of gravity, which, however, will descend again when allowed to do so. (2) *Unstable equilibrium* exists when a body tends still farther from its position after a very small disturbance. The centre is, in this instance, at its highest point. (3) *Neutral equilibrium* exists when a change in the position of a body neither raises nor lowers its centre of gravity. It remains in equilibrium in any position. This is exemplified by a perfect sphere on a level surface.

Laws of Falling Bodies.—All bodies fall with equal rapidity in a vacuum; but this is not true outside of a vacuum, for the air interposes resistance. A body falling freely in air has a variable velocity; its motion is not uniform. As has been seen, a force that acts on a body for a certain time, and is then withdrawn, imparts a velocity to the body proportional to the time during which it acted. According to Newton's law, a body in motion will remain so, unless acted upon by an external force, and this motion will be uniform. This will not be so outside of a vacuum, and the body, after a while, comes to rest. When force acts for some time, motion is uniformly accelerated; and the velocity imparted is proportional to the time during which it acts. At the end of a second, a body falling from rest has a velocity of 32 feet. This is expressed by saying that $g=32$. At the end of a given number of seconds, the velocity will be 32 multiplied by the number of seconds. If $v=$ velocity, and $t=$ the number of seconds,

$$v = gt.$$

At the end of 5 seconds, the velocity will be 32×5, expressed in feet per second.

The actual space passed through by a falling body, is 16.1 feet at the end of the first second; 64.4 feet at the end of two seconds; 144.9 feet at the end of three seconds, etc. The proportion for time, here, is 1, 2, 3, and for space, 1, 4, 9. The space passed through in the first second, 16 (which is one-half of 32 or g), multiplied by the square of the time, denote the distance at the end of the time. If $s=$ space,

$$s = \tfrac{1}{2} gt^2 = 16 \times t^2.$$

The velocity acquired by a body falling through a certain space is obtained by the formula

$$V = \sqrt{2 gs}.$$

The **balance** is an exemplification of the first class of levers. The ordinary balance has a beam, from each extremity of which is suspended a scale-pan. The fulcrum is called a knife-edge and rests with its sharp edge, or axis of suspension, upon two supports, which are formed of agate in order to diminish friction and thus insure sensibility and accuracy. Sensibility is also satisfied when the two arms of the beam are exactly equal; when the balance is in perfect equilibrium when the scales are empty; and, when, the beam being horizontal, the centre of gravity is in the same vertical line with the edge of the fulcrum and a little below the latter.

CHAPTER XLV.

ANIMAL MECHANICS.

In the body, all three classes of levers are found. Power is furnished by the muscles; the joints are the fulcrums; and the resistances are the weights to be overcome. (1) Examples of the first class are numerous. In raising the body from the stooping to the erect posture, the power is the hamstring muscles attached to the ischiatic tuberosity; the fulcrum is the hip joint; and the weight, the trunk and head. The maintenance of the head in the erect position; extension of the fore-arm after flexion; and extension of the raised foot are other examples. (2) Of the second class, depression of the lower jaw; and support of the body on the ball of the toes are examples. (3) Of the third class, flexion of the fore-arm; biting; and flexion of the foot are examples.

Standing.—In standing erect, the vertical through the centre of gravity falls between the feet. Especially is equilibrium stable, when the feet are separated. When the feet are close together, the base of support is small, and the slightest movement to either side will throw the vertical without. The position of the centre of gravity of the body as a whole, is in the vertebral canal, near the level of the upper border of the second lumbar vertebra. The vertical from the centre of gravity of the head passes in front of the atlas articulation; therefore, the head has a tendency to fall forward. The centre of the head, trunk and arms is in front of the tenth dorsal vertebra, at the level of the xyphoid process; and it is nearer the front the shorter the person. The vertical passes behind a line connecting the hip joints, and, hence, the tendency of these parts is to fall backward. The vertical through the centre of gravity of the head, trunk and thighs passes slightly behind the knee joints, and the tendency is to fall backward. The body, as a whole, tends to fall forward, as the vertical through the centre of gravity of the body as a whole, passes in front of the ankle joint. When standing on stilts, the same condition holds as when the feet are kept close together. It is impossible to stand on one leg, if one side of the foot and head be held close to a vertical wall, because the latter prevents one from throwing the centre vertically above the base of support.

In **sitting**, the vertical may pass through the tubera, in front of them, or behind them. Muscular effort or support prevents the body from falling forward or backward in the last two instances, while in the first, a very slight muscular effort maintains equilibrium.

Walking is the horizontal forward movement of the body by the alternate use of the two legs. That leg resting on the ground is the active—the other, which is swinging through the air, the passive leg. Landois divides walking into two acts: (1) The active leg is vertical, slightly flexed at the knee, and it alone supports the centre of gravity of the body. The passive leg is completely extended, and touches the ground only with the tip of the great toe. (2) For the forward movement of the trunk, the active leg is slightly inclined from its vertical position to an oblique and more forward one. For the trunk to remain at the same height, it is necessary that the active leg be lengthened. This is accomplished by completely extending the knee, as well as by lifting the heel from the ground, so that the foot rests on the ball; and lastly, by elevating it in the point of the big toe. During this movement, the tips of the toes of the passive leg have left the ground. It is slightly flexed at the knee-joint, and performs a pendulum-like movement, whereby its foot is moved as far in front of the active leg as it was formerly behind it. The foot is then placed flat on the ground, and the centre of gravity is now transferred to this active leg, which, at the same time, is slightly flexed at the knee and placed vertically.

The lateral movement of the trunk, made with the object of shifting the centre of gravity to the active leg, gives rise to the waddling gait seen in women and persons of heavy build. The trunk is inclined slightly forward to overcome the resistance of the air; and, during the pendulum-like movement, rotates on the head of the active femur. This rotation is compensated by the swinging of the arm of the same side in the opposite direction. The length of the step depends on the leg of the individual.

Running differs from walking in that for a short time, both feet are off the ground together, and the body is in the air. The active leg, as it is forcibly extended from a flexed position, gives the necessary impetus.

In **leaping,** the hip, knee and ankle joints, previously bent in the opposite directions, are suddenly extended, both legs leaving the ground at the same time. The muscular effort made is more than sufficient to straighten the limbs, and an impulse is therefore imparted to the centre of gravity of the body which is thus propelled, like a projectile, in the mean direction of the joints thus extended.